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JANUARY 1926

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PUBLISHED MONTHLY BY THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
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American Institute of Electrical Engineers

COMING MEETINGS

Midwinter Convention, New York, N. Y., February 8-11

Annual Business Meeting, New York, N. Y., May 21

Annual Convention, White Sulphur Springs, W. Va., June 21-25

Pacific Coast Convention, Salt Lake City, Utah, (Dates to be announced in subsequent issue)

Regional Meetings

Middle Eastern District, Cleveland, Ohio, March 18-19

Great Lakes District, Madison, Wis., (early in May)

Northeastern District, Niagara Falls, May 26-28

MEETINGS OF OTHER SOCIETIES

New York Electrical Society, Engineering Societies Bldg., New York, N. Y., January 6

Convention of Institute of Radio Engineers, Engineering Societies Bldg., New York, N. Y., January 18-19

Annual Meeting of American Society of Civil Engineers, Engineering Societies Bldg., New York, N. Y., January 20-22

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Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

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Lighting and Continuity of Service

In spite of the great development within the last few years of devices for the protection of electrical apparatus against lightning and the vast improvement in the insulation of transmission lines, this source of disturbance still remains one of the most serious threats against continuity of service in our large overhead systems. In perfecting remedies, or preventatives, it is highly desirable to know the cause and nature of the attack of lightning on the line, for it is on the transmission line rather than in the station, that interruptions to service usually occur.

Lightning *may* as a theoretical matter affect a transmission line either by electrostatic induction; that is, by the release of a bound charge that has been gradually drawn onto the line, or by direct stroke from the atmosphere which may be a heavy and conspicuous stroke or a minor, almost unnoticed flash. As a practical matter, especially when considering the installation of one or more ground wires over a transmission line, it is important to know which sort of action is dominating. Mr. Peek has pointed out that under certain conditions of cloud discharge we may expect a voltage to appear on a transmission line from the release of a bound charge sufficiently high to flash over even a 220-kv. insulator string. Of this there can be little doubt. On the other hand, some considerations may be raised tending to indicate that the line will in all probability actually be subject to direct strokes, *usually of a minor magnitude.* This may be reasoned as follows:

It can hardly be doubted that on all occasions when a person notes a flash and thunderclap substantially simultaneously, (and this happens to the average individual several times a season), this means a lightning flash within one or two hundred feet, since sound travels about 1000 ft. per second. Yet it may be years before any notable lightning damage occurs in any one village or town. This clearly means that most discharges are of very limited energy or severity and find some path to ground without leaving any trace, presumably, usually down tree trunks. There is further ample direct evidence that strokes of minor severity do actually occur. It would seem to follow, then, that there is every reason to suppose that transmission lines, extending for many miles and being twenty to fifty feet in the air and usually free of the protection of trees, will be actually struck occasionally by these low-power strokes, which, while of low power so far as the ability to do conspicuous damage is concerned, are of sufficiently high voltage to flash over insulators.

This view is strongly supported by the evidence of the record of lightning disturbances on the Taylors Falls line* where many insulators were shattered without power on the line, and some poles were splintered, a condition which could hardly be caused by any charges induced on line conductors.

Considering the use of overhead ground wires as a means of protection, we have the following considerations to indicate some material practicable limitations in the effectiveness of overhead ground wires. Consider a transmission line with ground wire protection just the moment before the discharge of the cloud by a lightning stroke. A considerable bound charge has been drawn to the surface of all the conductors and of the ground wires but the potentials are normal. The instant the cloud is discharged, these bound charges raise the potential of all the wires, conductors and ground wires alike to appropriate voltages which may be very high. So far, the presence of the ground wire is no relief to the voltage on the conductor. But the charge on the ground wire is free to run to earth through the tower, which it does; and *when the potential of the ground wire has fallen toward earth potential* sufficiently, it establishes a static capacity to the line conductors, and this tends to reduce the potential produced by the original bound charge. This might be of very material benefit, except that in all probability, (at least with long span construction), the time required to empty the charge on the ground wire through the tower into the ground through whatever ground resistance may exist, is enough to give the charges on the conductors time to flash over, if they are at sufficiently high voltage to do so.

Of course, the presence of the ground wire tends to reduce the original bound charge on the conductors, since the flux from the ground wire must traverse much of the same path as the flux from the conductors, but the numerical relations are such that at least with six conductors and one ground wire, the effect of the seventh wire must be almost negligible.

However, broadly speaking, from the point of view of absolute continuity of service, since it must be admitted that occasional failures due to one cause or

*Reference. Three papers. A. I. E. E. TRANSACTIONS, Vol. XXVII, Part 1, 1908, By J. F. Vaughan, pp. 397, N. J. Neall, pp. 421, P. H. Thomas, pp. 755. A review of these three papers treating this remarkable set of records will be well worth while to a person interested in the attack of lightning on transmission lines.

another must occur on any line, the use of independent lines, double circuit or single circuit as may be most suitable, running by separate routes would seem to be the only way of getting continuous service.

Percy H. Thomas

Some Leaders of the A. I. E. E.

Lewis Buckley Stillwell, the twenty-second president of the American Institute of Electrical Engineers, was born in Scranton, Penn., March 12, 1863. He prepared for college at the Scranton High School; matriculated at Wesleyan University in the class of 1886; transferred to Lehigh University at the end of his sophomore year and completed the course in Electrical Engineering at that institution in 1885, following this by special work in mechanical engineering during the next academic year.

In October, 1886, he entered the employ of the Westinghouse Electric Company at Pittsburgh, and before the end of that year became Assistant Electrician of the company, which position he retained for about five years. During this period, he was actively associated with George Westinghouse, O. B. Shallenberger, William Stanley, Albert Schmid, Nikola Tesla, Charles F. Scott and others, in the rapid development of the alternating current system.

In 1889 and 1890, he was sent to Europe as technical adviser to the British Westinghouse Company and traveled extensively in Great Britain and on the continent, investigating the development of alternating current and other electric systems.

In 1890, while in London, he first met Mr. Edward D. Adams, President of the Cataract Construction Co., and Dr. Coleman Sellers, its Chief Engineer, who were investigating the problem of power development and distribution at Niagara Falls, and from that time until the adoption of the polyphase system and award of the initial Niagara contract to his company, his attention was closely concentrated upon the development of electrical machinery for power transmission.

As Electrical Engineer of the Westinghouse Company, he installed the first three 5000-horse power units at Niagara.

Resigning from the Westinghouse Company and occepting appointment as Electrical Director of the Niagara Falls Power Co., he removed his residence to NiagaraFalls, *and* devoted three years to the extension and completion of power plant No. 1, with local distribution and transmission to Buffalo. During this period, he assumed responsibility for the operation of the plant as well as for the electrical engineering incident to its increase from the original three 5000-horse power units to eleven units.

While at Niagara, he invented and patented the first time-limit circuit-breaker and the diagrammatic switchboard control, these inventions together with the induction regulator, patented in 1888, being among the most important inventions upon which the successful transmission and distribution of alternating-current power has since depended.

In 1899, while still at Niagara, he was appointed by the Manhattan Railway Company Consulting Electrical Engineer, and in that capacity had charge of the electrification of the elevated railways in Manhattan and the Bronx. For something over a year, he divided his time between Niagara Falls and New York City, and, in September, 1900, the first power house unit at Niagara having been completed, and the commercial success of transmission to Buffalo having been demonstrated, tendered his resignation as Electrical Director of the Niagara Companies and established his office as Consulting Engineer in New York.

In 1900, he was appointed Electrical Director of the Rapid Transit Subway Construction Co., and during the next eight years directed the electrification of the New York subways.

In addition to the electrification of the elevated and subway lines in New York, some of his more important professional engagements included consulting engineer for the following:

Consulting Engineer, Hudson Companies, in charge of electrical, mechanical and rolling stock equipment, 1905-1913. Member, Erie Railroad Electric Commission, 1906; United Railways & Electric Co., Baltimore; Interborough Rapid Transit Company; N. Y., New Haven & Hartford R. R. Co., (Hoosac Tunnel Electrification); N. Y., Westchester & Boston Railway Co.; Lehigh Navigation Electric Co., N. Y.; Municipal Railway Corporation; N. Y. State Bridge & Tunnel Commission; and N. J. Interstate Bridge & Tunnel Commission. He was also a Member of the Board of Economics & Engineering, National Association of Owners of Railroad Securities, 1921-1922.

As Consulting Engineer to the Lehigh Navigation Electric Company, in cooperation with his associates, M. G. Starrett, John Van Vleck and the late H. S. Putnam, he designed and supervised the construction of the initial 45,000-kw. power plant at Hauto, Penn., with its distribution system—the first large power plant erected in America at the "mouth of the mine."

During the war, he served as a member of the National Research Council.

Mr. Stillwell is a Fellow of the American Institute of Electrical Engineers, Past-President of the American Institute of Consulting Engineers (two terms), member of the National Academy of Sciences, the American Society of Civil Engineers and of the British Institution of Electrical Engineers.

He is a Life Trustee of Princeton University, and for three years served as a member of the Board of Directors of the United States Chamber of Commerce—the only man elected to that body to represent the engineering profession.

Theory of the Autovalve Arrester

BY JOSEPH SLEPIAN[1]

Member, A. I. E. E.

***Synopsis.**—The advantage of valve type arresters for high-voltage, power-system protection is briefly discussed. The theory of the autovalve arrester is given.*

I. Induction and Regulation of Surges

IN the last few years, considerable light has been shed on the manner of induction of high voltage on power systems by lightning,[2] and some estimates of the magnitudes involved have been made. Charges on clouds produce electrostatic fields extending down to the ground, which induce charges on power lines. The vertical gradient at the earth's surface due to these fields has been estimated[3] to be of the order of 100 kv. per ft. When the inducing charges on the clouds disappear suddenly by a lightning discharge, the induced charges on the power lines produce voltages to ground equal to the height of the lines multiplied by the inducing gradient, and, therefore, of the order of hundreds of kilovolts. The induced charges may be a few miles in extent.[4]

The power line becomes then a source of voltage, so high as to be dangerous to connected machines, and the very important question arises when considering the possibility of relief by lightning arresters as to what is the regulation of this source of voltage. It is now well recognized[5] that voltage due to a free charge of this type on a power line regulates like a generator having an internal resistance of a few hundred ohms. Hence the voltage can be quickly materially reduced if, and only if, sufficient current is drawn from the line. An arrester will be effective, if, and only if, it draws nearly two amperes per kilovolt of induced surge[6]. An arrester then must be able to discharge hundreds of amperes with only a moderate rise of voltage.

II. Energetics of Surge Dissipation

The large current which must pass through an arrester if it is to be really effective introduces great difficulties in the design of arresters of the arc-resistance type for higher voltage circuits. This is not due to the energy of the surge itself, which is only moderate in amount because of its short duration, but to the energy supplied by the normal working voltage, which lasts throughout the whole arcing period, and may be from one-half cycle to several seconds. For example, a surge 1.86 mi. long, will discharge for only 1/100,000 sec. If an arrester connected to a line, the normal voltage of which to ground is 10,000 volts, discharges 900 amperes from this surge and reduces the voltage thereby to 30,000 volts, the energy involved will be only 30,000 by 900 by 1/100,000, or 280 watt-seconds. On the other hand, if the normal line voltage discharges 300 amperes for one half cycle, or 0.0083

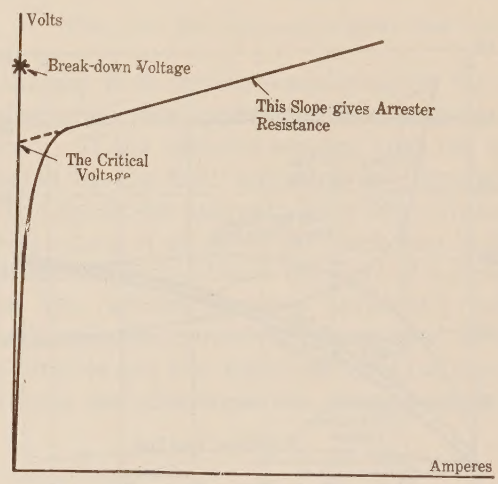

FIG. 1—THE VALVE CHARACTERISTIC

second, the energy will be 10,000 by 300 by 0.0083 or 24,900 watt-seconds, or more than 90 times the energy due to the surge alone.

Valve type arresters, being built up of elements having the characteristic shown in Fig. 1, are not subject to the disadvantage of disposing of this large draft of energy from the normal voltage. With the passing of the surge, and the restoring of normal voltage, the discharge ceases. It is, therefore, entirely practical to construct valve type arresters with adequate discharge capacity for even the highest voltages.

Some illuminating calculations made for an arrester set at the center of a freed charge as shown in Fig. 2 are given in the curves of Fig. 3. The initial surge voltage is taken as 250 kv. The normal voltage to

1. Research Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

2. A. L. Atherton, TRANS. A. I. E. E., Vol. XLII, p. 179 (1923); E. E. F. Creighton, TRANS. A. I. E. E., Vol. XLI, p. 52 (1922); D. W. Roper, TRANS. A. I. E. E. Vol. XXXIX, p. 1895 (1920); C. P. Steinmetz, TRANS. A. I. E. E., Vol. XXXIX, p. 1941 (1920).

3. F. W. Peek, TRANS. A. I. E. E., Vol. XLIII, (1924); H. Nörinder, *Electrical World*, Feb. 2, 1924; E. E. F. Creighton, TRANS. A. I. E. E., Vol. XLIII, (1924).

4. H. Nörinder, loc. cit.; F. W. Peek, loc. cit.

5. H. Rudenberg, "Elektrische Schaltvorgange," Berlin 1924, p. 330.

6. E. E. F. Creighton, TRANS. A. I. E. E., Vol. XLII, p. 179 (1923).

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 8-11, 1926.

ground is taken to be 8660 volts, and the line surge impedance, 400 ohms. The heavy line curves show the reduction in voltage for varying resistance in an arrester of the arc type and one of the valve type with critical voltage, 10,000 volts. Evidently suitable protection is not obtained until the arrester resistance is less than 50 ohms.

The light lines show the energy dissipated in the arrester. In order to get the curve for the valve type well into the picture, it is necessary to consider a surge 400 mi. long; the more reasonable surge length, 4 mi. would be barely visible on the scale chosen.

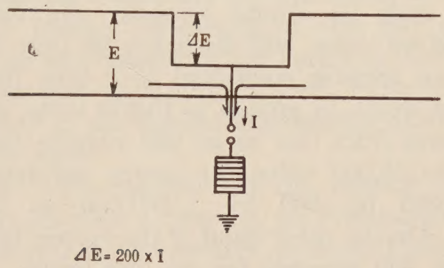

Fig. 2—Basis of Calculation of Fig. 3

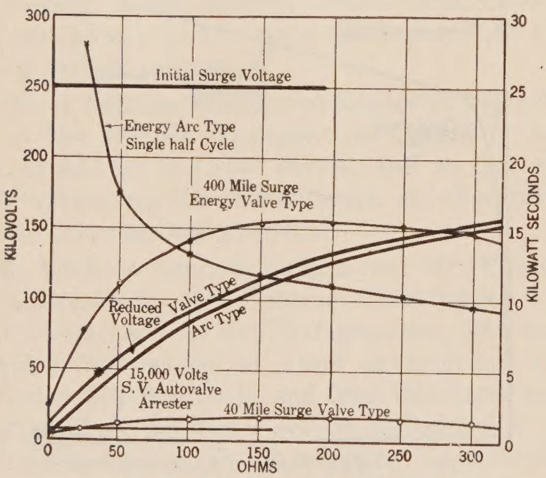

Fig. 3—Energetics of Surge Dissipation

The energy relations illustrated in Fig. 3 have proven determining factors. The only practical arresters with adequate discharge capacity for high-voltage lines are the valve type arresters.

III. Modern Valve Types

The so-called valve characteristic, shown in Fig. 1, has been frequently discussed, and the terminology indicated in the figure is generally used. Conducting systems having this characteristic are numerous in nature. However, in most of these systems the critical voltage is too low (as in contacts or electrolytic polarization cells) or the current which may be carried is too small, (as in thermionic or low-pressure gas tubes), to be useful for lightning arresters for power lines. So far the only systems which have been found to possess the valve characteristic to a necessary degree have been certain films which are made conducting by application of sufficient voltage, but which are subject to constant repair action, requiring the continued application of the high voltage for the maintenance of the conductivity and in which the original resistivity is restored when the voltage is reduced. Three practically used arresters have been developed utilizing films of this type.

The Electrolytic Arrester. The film in this arrester consists of a layer of gas-laden, aluminum oxide, which forms on an aluminum anode in a suitable electrolyte. Application of a few hundred volts breaks this film down, but the flow of current brings about a repairing electrolytic action.

The Oxide Film Arrester. In this arrester, the film is initially a layer of varnish, which, in use, is gradually replaced by litharge, PbO. The repairing action lies in the thermal effect of the current upon lead peroxide, which reduces it to litharge at the points of breakdown of the film.

The Autovalve Arrester. Here the film is a thin layer

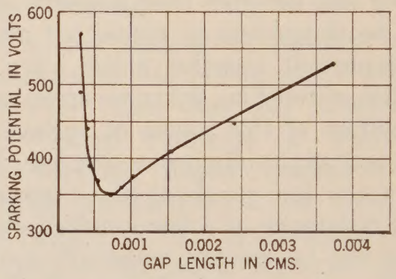

Fig. 4—Sparking Potential for Short Air-Gaps

of air next to a cold cathode which is the seat of the cathode drop in a glow discharge. With the application of sufficient voltage, this air film becomes highly ionized, but the discharge of these ions into the electrodes and recombination quickly restore the normal resistivity when the voltage is reduced.

IV. The Breakdown of Air Between Parallel Plane Electrodes

Since the active element in the autovalve arrester is air, any explanation of the arrester's design and functioning must include a discussion of the properties of air with respect to electrical breakdown and resulting conductivity. Fig. 4 shows the relation between breakdown voltage and distance between parallel plane electrodes. A striking feature of this curve is the minimum at electrode separation of 0.001 cm., so that shorter separation than this requires increased voltage for breakdown. This remarkable fact is readily explained by the current theory of ionization by collision[7].

7. J. J. Thomson, "Conduction of Electricity in Gases," p. 381 J. S. Townsend, "Electricity in Gases," Chap. VIII and IX.

The existence of a minimum breakdown potential of about 350 volts for short gaps may seem contradictory to experience. For example, a widely used type of telephone protector consisting of two small carbon blocks separated by 0.002 in. will usually break down at 200 volts, or sometimes even less. In this case, however, the breakdown is due to the lining up of carbon dust particles in the intense electric field so that a conducting bridge which starts an arc is formed. If precautions are taken to prevent contacts taking place in this or any other manner, the existence of a minimum breakdown voltage may be shown experimentally.

In the autovalve arrester, as will be explained later, it is necessary to use gaps between resistance material electrodes with a breakdown voltage of little more than 350 volts. The curve of Fig. 4 indicates that an electrode separation of 0.0003 in. is necessary for this. At first sight, so minute an electrode separation would appear impracticable in a commercial arrester.

This difficulty was overcome in the early experimental autovalve arresters by merely placing the resistance electrode disks in contact. Due to the resistivity of the electrode material, the gap would not be short-circuited at the contacts. At the same time,

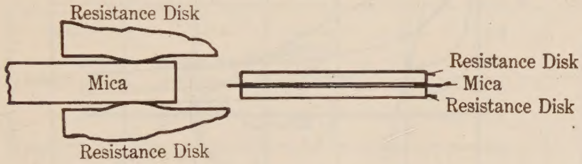

Fig. 5—The Autovalve Gap

in the neighborhood of each contact, there would be points at which the electrode separation was 0.0003 in., and there, breakdown at 350 volts would occur.

A better solution now used was found later and consists in using a mica spacer, 0.003 to 0.005 in. thick, placed directly between the disks. Fig. 5 shows the standard autovalve element (right) and section at the mica spacer, highly magnified (left). The mica, having a dielectric constant of six to seven, distorts the electrostatic field, very much as if it were conducting. Thus there is a concentration of electrostatic stress at the corners of the mica. Due to inherent variations in the nature of the surface of the resistance disk and its contact with the mica spacer, the total voltage applied is not expended symmetrically between the two disks and the edges of the mica, but at some points nearby, all the voltage appears between one resistance disk and the adjacent mica edge, and at other points between the other resistance disk and adjacent edge. Hence, when a little more than 350 volts is applied, these highly stressed points break down and precipitate the discharge of the whole gap. Numerous tests have shown that in commercial autovalve arresters, the breakdown of the column of disks is less than 400 volts per gap.

This expedient of using the electrostatic influence of the mica spacer to precipitate the discharge at low voltage is not practically useful if metal electrodes are used. The discharge must start at the mica, and if it is permitted to concentrate at its point of origin, as with metal electrodes, the mica is quickly destroyed. In the autovalve arrester relatively high resistivity electrodes are used, which limit the intensity of the discharge next to the mica. Hence, thousands of discharges may be sent through it with no deterioration of the mica.

V. Electric Discharges in Air

Arc Discharge. The breakdown of a gap is due to the ionization produced by the high electrostatic gradient.

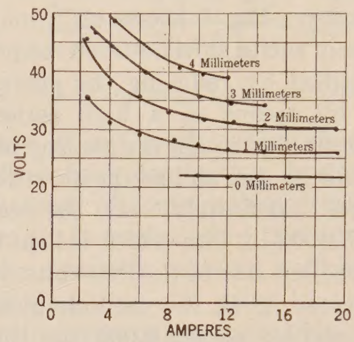

Fig. 6—Arc Characteristics for Copper

If the gap is to remain conducting for the duration of a discharge, this ionization must somehow be maintained. If the cathode remains cold the ionization is effected by the field becoming so distorted that with carbon electrodes approximately 350 volts are impressed across a layer of air 0.001 cm. thick next to the cathode. The discharge then takes the form of a glow. If, however, the cathode becomes sufficiently hot for thermionic emission, much less voltage need be expended at the cathode and the discharge takes the form of an arc.

In the arc discharge the voltage expended at the

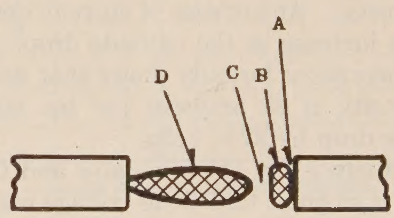

Fig. 7—The Glow Discharge (magnified)

cathode must be sufficiently great to maintain the cathode at a temperature sufficiently high for thermionic emission, and also must be sufficiently great, and concentrated on a sufficiently small space next to the cathode, so that the electrons liberated thermionically will ionize by collision. Twenty volts is sufficient for both these purposes for most electrode materials.

In addition to the voltage expended at the cathode some must be expended in carrying current in the remainder of the discharge. This additional voltage is found to vary inversely as the current strength, so that characteristics such as shown in Fig. 6 are obtained.

It is now clear why an arc discharge is not suitable for giving the valve characteristic to a gap. Aside from the melting or burning of the cathode due to its necessary high temperature the voltage of the arc discharge is too low, (about 20 volts for short gaps) in comparison with the lowest reliable gap breakdown of about 350 volts.

Glow Discharge. When the cathode is too cold for thermionic emission the glow form of discharge takes place in which the ionization is primarily produced by ionization through collision due to high gradient in a film of air about 0.001 cm. thick next to the cathode. The voltage expended in this film is about 350 volts for carbon electrodes. Fig. 7 shows on a magnified scale the appearance of such a glow between copper electrodes. This was obtained by reducing the current to a few milliamperes by means of a high series resistance. When the current is so small, the heating of the cathode is insufficient for an arc, and so the glow discharge may be maintained indefinitely. *A*, the cathode dark space, is the 0.0003-in. film which is kept broken down by the high gradient due to the 300 volts (cathode drop for copper) across it; *B*, the cathode glow is a highly ionized blue region, about 0.005 in. thick. *C*, the Faraday dark space, is also highly conducting, and is about 0.010 in. thick. *D*, the pink positive column, extends to the anode.

So long as the cathode is not completely covered by the discharge, the cathode drop and the cathode current density are approximately independent of current, the cathode glow simply increasing or decreasing in area as the current is varied. The cathode drop and current density do vary with the nature of the cathode; for carbon, the cathode drop and current density are respectively about 350 volts, and 10 amperes per cm².

When the cathode is completely covered by glow, further increase of current must of course increase the current density. An increase of current density causes a moderate increase in the cathode drop. Extrapolation of a theoretical formula shows that an increase in current density of 25 amperes per sq. cm. increases the cathode drop by 37½ volts.

The conductivity of the blue glow and the Faraday dark space is so great that little voltage is consumed in these parts. In the pink column, however, the resistivity is greater, and for small currents, the gradient in it may amount to over 5000 volts per cm. However, this gradient decreases, as the current increases.

Volt-ampere characteristics of a glow between copper electrodes are shown in Fig. 8. The longer gap lengths show a falling characteristic due to the properties of the pink positive column. For the 0.1 mm. gap, the positive column is completely eliminated and so, a flat characteristic is obtained.

Transition from Glow to Arc Following Sparkover. At the moment a spark-gap is broken down by high voltage, the electrodes and, in particular, the cathode are, of course, cold. It follows, then, that the discharge must begin as a glow. After a short but finite time, the energy input at the cathode, due to the glow, heats some spot to such a degree that thermionic emission begins there. The cathode drop then falls to about 20 volts and the current concentrates at the point to sufficient degree to maintain the point hot. For a definite time, then, immediately following a sparkover, the discharge is in the form of a glow.

Heating of Autovalve Disk. It would seem, then, that if the time taken between the sparkover of a gap and the transition from the resulting glow into an arc is long compared to the duration of a surge, it should be very easy to make a lightning arrester which would only discharge in glow form. It is easy to get an estimate of the time involved. The formula given on page 98 of "Mathematical Theory of Heat Conduction,"

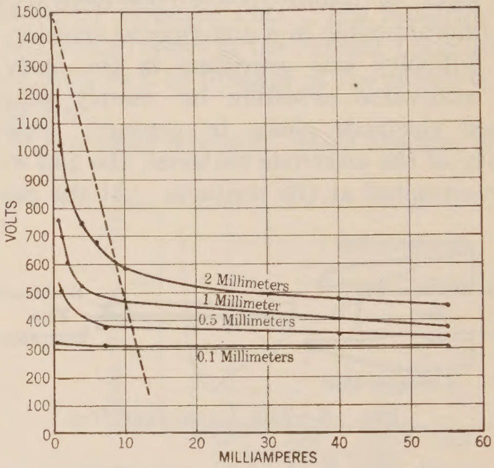

Fig. 8—Glow Characteristics for Copper

Ingersoll and Zobel, Ginn & Co., may be readily transformed into

$$T = \frac{W}{4.18 \sqrt{k\, c\, \delta}}$$

where k, c and δ are heat conductivity, heat capacity and density, respectively of the material making up an infinite solid; W is the power input per unit area on an infinite plane surface in that solid, and T is temperature rise at that surface. Units are deg. cent., small calories, grams, centimeters and watts.

For the resistance material electrodes used in the autovalve arrester, $c = 0.185$ cal. per gr., $k = 0.016$ cal. per cm². per deg. cent. per cm³. $\delta = 2.0$ gr. per cm³. For a glow discharge at normal current density we have approximately 10 amperes per cm². at 350 volts, giving $W = 3500$. Using these numerical values, we get the curves shown in Fig. 9. Remembering that each one-thousandth of a second corresponds to 186 miles of surge, it is evident that the heating of the electrode surface is so slow that in any surge of practical length the temperature rise will be only a few degrees; hence the discharge will still be in the glow form when the surge has ended, and if the normal line voltage per

disk is less than glow voltage, the discharge will stop when the surge voltage disappears.

Current Concentration at Inhomogeneities. So far, it would appear from the formula for the surface temperature rise under a glow that the most desirable materials for electrodes would be those having the highest thermal conductivity and capacity. Metals, then would seem to be particularly suitable, and one would expect to find them superior to the resistance material used in autovalve arresters. However, when put to test contrary results are obtained. With metal electrodes, a heavy discharge only ten microseconds long, will usually end as an arc, whereas, with autovalve arrester disks, it will still be a glow for a discharge 100 times as long. Some as yet unconsidered factor is playing a part here. This factor is the great current concentration in the glow which takes place at any points of the metal surface which happen to have a lower cathode drop than the rest of the metal surface.

It has been mentioned before that the cathode drop

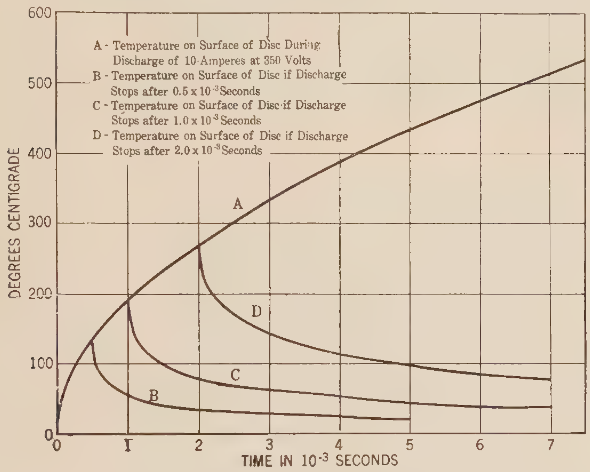

Fig. 9—Temperature Rise of Resistance Material Cathode

in a glow discharge is a function of the material making up the cathode, being 350 volts for carbon, 300 volts for copper, 250 volts for iron, etc. However, like other properties of surfaces, these cathode drops are not absolute constants of the material, but vary somewhat depending upon the state of the surface. Films of absorbed gas or moisture change the cathode drop by a small amount. Dust particles or adhering impurities of any kind may lower the cathode drop enormously. The alkali metals and their oxides are particularly effective in this respect, and may lower the cathode drop to less than 150 volts.

Now imagine on a cathode carrying a glow discharge a point at which the cathode drop is a few volts less than that of the rest of the surface. It is evident that instead of a uniform current distribution over the cathode surface at the moderate density of ten amperes per cm²., there will be concentration of current at the point of low cathode drop. This point will heat up very much faster than is indicated by Fig. 9, and the transition from glow to arc will take place in a much shorter time.

Another effect which is even more important for very short gaps in hastening the transition from glow to arc, is the lining up of minute conducting dust particles, under the intense electrostatic field. In the cathode dark space, the electric gradient is of the order of 350,000 volts per cm. The mechanical force on conducting particles in such fields is relatively enormous, and there is a tendency for these particles to form into chains almost instantly. In very short gaps, five mils or less, these chains bridge the electrodes and start arcs by the current concentration in them with resulting rise in temperature.

Fig. 10—Current Flow at a Contact

Temperature of a Contact. The effects of surface inhomogeneities and conducting bridges in causing premature heating of some cathode surface point and striking of an arc is combated in the autovalve arrester by giving the electrode material sufficient resistivity. We may say that if at any point less voltage is consumed in the discharge or gap space than at other points, then this difference of voltage will be expended on the resistance of the path offered to current immediately behind this point in the electrode material. Conditions are then very similar to those which take place at a

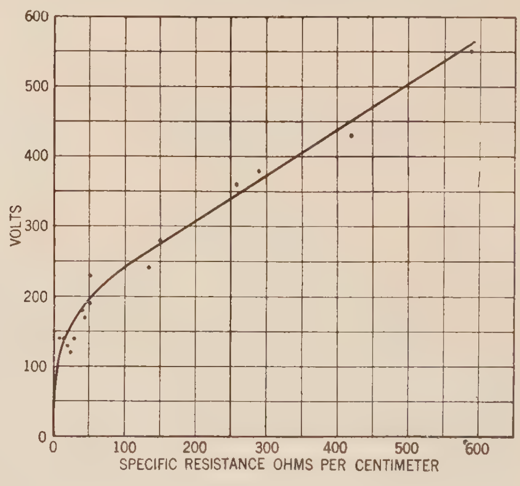

Fig. 11—Voltage to Draw on Arc by Contact

point of contact between electrodes as illustrated diagrammatically in Fig. 10, the arrows indicating the lines of flow of current. It is not difficult to calculate the approximate temperature rise at such a contact, if the contact area is assumed circular. It is

$$T = \frac{E^2}{33\, k\, \rho}$$

where, E is the voltage on the contact, and

k and ρ are the thermal conductivity and electrical resistivity, respectively, of the electrode material. Because of the very small thermal capacity of the

contact, this temperature rise is almost instantaneous. If copper electrodes were used with $k = 1.0$ and $\zeta = 10^{-6}$, a surface inhomogeneity or conducting bridge which would throw 10 volts onto the electrode material at a point would give a temperature rise of

$$T = \frac{100}{33 \times 1 \times 10^{-6}} = 3 \times 10^6 \text{ deg. cent.,}$$

so that an arc would form instantly. Autovalve electrodes on the other hand with $k = 0.016$ and $\rho = 20$ give

$$T = \frac{100}{33 \times 0.016 \times 20} = 9.4 \text{ deg. cent.,}$$

or a practically negligible increase in the tendency to strike an arc.

Experiments on Arc Drawing at a Contact. The considerations given above show that the voltage necessary to start an arc by contact, increases with the resistivity of the electrode material. The results of experiments confirming this are shown in Fig. 11.

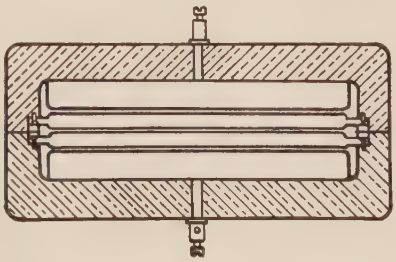

FIG. 12—THE THOMAS ARRESTER

The parabolic relation found between voltage and resistivity is predicted by the formula,

$$T = \frac{E^2}{33\, k\, \rho}$$

Design of Autovalve Arrester. The three essential parameters in the autovalve arrester element which determine its electrical performance, are gap length, electrode resistivity, and electrode area. A desirable characteristic is a discharge voltage only little less than the breakdown voltage, and this with a minimum of resistivity in the electrode material so that impractically large area will not be necessary for adequate discharge capacity.

From Fig. 8 it would appear that if the current density is sufficiently limited, a discharge voltage nearly equal to the breakdown voltage may be obtained. Thus the valve characteristic may be obtained for any gap length if only electrodes of sufficiently high resistivity are used. It is very interesting that this principle was understood and described seventeen years ago by P. H. Thomas in his U. S. Patent No. 882,218. Fig. 12 shows his proposed arrester. Quoting from his patent, "It is an essential characteristic of my invention that there shall be an opportunity for a large number of independent static discharges between the discharge plates and that each discharge path shall have such resistance that the dynamo current cannot follow the static discharge."

However, it is only by using very short gaps with a few hundred volts breakdown, that resistivity sufficiently low for a practical arrester may be used. To see this, consider again the curves of Fig. 8 for glow discharge between copper electrodes. Suppose that by using mica spacers or otherwise, a 2-mm. gap could be broken down by 1500 volts. Then the current and voltage of the discharge would be determined by the intersection of the 2-mm. glow curve, and the straight line drawn from 1500 volts on the voltage axis, with a slope equal to the resistance of the circuit. The line shown in the figure corresponds to a resistance of 102,500 ohms, and with this resistance, the discharge voltage is only 600 volts. If the discharge voltage is to be raised up to 20 per cent less than 1500 volts, that is 1200 volts, the line must be swung around until it corresponds to a resistance of 440,000 ohms. At its point of intersection with the 2-mm. glow curve the current will now be one milliampere. Taking 10 amperes per cm². as the current density in the glow this gives 0.001 cm². as the area. The resistance in an electrode up to such an area is given by $\frac{0.261}{a}\rho$ where ρ is the resistivity of the material, a is the radius of the area, in this case 0.0056 cm. Thus, $\rho \times 46.6 = 440{,}000$ or $\rho = 9400$ ohms per cm³. This is prohibitively large. If, however, the gap length and breakdown voltage are lessened, the resistance necessary to keep the discharge voltage nearly equal to the breakdown voltage decreases, and when 0.1-mm. gap with 350-volt breakdown is reached, no resistance is necessary for keeping up the discharge voltage.

For a practical arrester, then, it is necessary to use a gap so short that its glow volt ampere curve is substantially flat. This will occur if the glow has no positive column and from the dimensions given in connection with Fig. 18, this means a gap length not over 0.015 inch. In the commercial autovalve arrester, gap length of not over 0.005 inch is used to ensure breakdown at little more than 350 volts.

With gap lengths less than 0.015 inch the resistivity of the electrode material must be made only high enough to take care of surface inhomogeneities and the partial contacts due to bridging particles. These are not calculable, and the permissible low limit resistivity must be determined by test. The low limit for resistivity in commercial autovalve arresters at present is 20 ohms per cm³., giving a total resistance of only a fraction of an ohm per disk.

The gap length and resistivity being thus given, the area of the electrodes will determine the discharge rate of the arrester. In the *S V* type of autovalve arrester the area has been chosen to give a discharge rate equal to that of the electrolytic arrester.

Carrying Capacity of 60-Cycle Busses for Heavy Currents

BY TITUS G. LE CLAIR[1]

Associate, A. I. E. E.

Synopsis.*—Up to the present time it has seldom been necessary to design busses for carrying capacity above 2000 or 3000 amperes. Within the last few years we have passed this mark, and we shall soon be required to design busses for very much larger capacities.*

For simple geometrical designs there are formulas from which we may calculate the capacities of large busses. These simple designs cannot be easily mounted, and for this reason we must resort to styles which are easier to construct. These types cannot be calculated readily by the mathematics available to the ordinary engineer. This paper is presented with the idea of giving a ready reference for determining bus capacities without involved calculations.

Curves are given showing the carrying capacity of a few types which are proposed as standards, and, in addition, a few curves compiled from tests showing the distribution of current in busses to show the necessity of this type of design. By a little careful study of these curves, the average designer may quickly choose the type of bus which will best meet his requirements for carrying capacity and allowable space. All busses are designed on the basis of 30 deg. cent. temperature rise, and their ratings may be proportionately increased if the conditions warrant a 40 deg. temperature rise.

As the usefulness of electric power becomes more and more widespread and its uses more diversified, large blocks of power are frequently required in a small space. This is especially true in factories where there may be a great many machines on a small floor area with individual motor-drive, or for electric furnace work. In consequence, we find it necessary to supply large blocks of power at low voltage, with correspondingly heavy currents.

As the transmission system grows in size the energy of short circuit on the high-tension system is so great that the cost of protective apparatus, as well as the expense of insulating for high voltage, requires that all power be supplied from large, well protected transformer banks in fire-proof vaults. This means that very heavy currents must be brought out from the transformer bank to the distribution switchboard or to the furnace through a single low-tension bus. Due to this rapid development it has become necessary within the last few years to design busses far beyond the old limits of 2000- or 3000-ampere capacity, with the time not far in the future when we shall need to carry 10,000 amperes or more on a single low-tension bus.

Theory

In any d-c. circuit, be the conductor solid, laminated or stranded, the current divides in all parts in proportion to the resistance, which means that with a conductor of homogeneous material, the current is practically the same in all parts. The same condition does not hold true, however, for alternating current. In addition to the resistance drop, an alternating current introduces an alternating flux surrounding any element of the conductor. This alternating flux generates a voltage which tends to oppose the flow of current in the conductor element. When we consider a large conductor, it is obvious that the lines of force caused by an element in the outer part surround the entire conductor, but, for a central element, some of the flux does not cut the outer element. The result is that the effective impedance of an element in the central part of the copper is higher than in the outer edge, thereby forcing most of the current to the outer surface, producing the so-called skin effect. In very large conductors this can be carried so far as to have the current in the center of the bus very nearly in the opposite direction to the current in the outer part of the bus, as well as being smaller in magnitude.

When the phases are placed close together there is, in addition to the skin effect, a voltage induced by the flux from an opposite phase which is not uniform over the entire conductor and forces current toward the near side. This is called the proximity effect. Both the skin effect[2] and proximity effect[3] can be calculated for cylindrical or tubular conductors from formulas developed by H. B. Dwight.

Unfortunately, it does not often pay, due to the difficulty of mounting and of making connections, as a practical problem to use a circular conductor for very large bus work. Former practise has been to build the bus of laminated copper bars for the required capacity. For a bus of this shape, it is impracticable, if not utterly impossible, to calculate the distribution of current in order to obtain the losses and temperature rise on alternating current circuits. To further complicate the problem nearly all high capacity busses are three-phase and not single-phase, which makes it more difficult.

Tests

Due to the demand for large increases in bus capacity and the impossibility of making calculations, we have just completed a series of tests to determine, if possible, an efficient and practicable type of bus construction for very high currents.

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1. Of the Commonwealth Edison Co., Chicago.

To be presented at the Midwinter Convention of the A. I. E. E., to be held in New York, Feb. 8-11, 1926.

2 *Skin effect in Tubular and Flat Conductors*, H. B. Dwight, A. I. E. E. Vol. XXXVII, p. 1379.

3. *Skin effect and Proximity Effect in Tubular Conductors*, H. B. Dwight, Journal A. I. E. E., Vol. XLI, p. 189.

In order to make these tests applicable to heavy currents and three-phase circuits, a three-phase bus, 20 ft. long was set up and connected in the circuit between the transformer and three of the rings of a 3900-kw., 230-volt, rotary converter. (See Fig. 1.) This converter could be operated in parallel with another machine on the d-c. side and permitted a ready control of the current up to quite high values. Practically all tests were run with constant current to determine the ultimate temperature rise of the various types of bus construction.

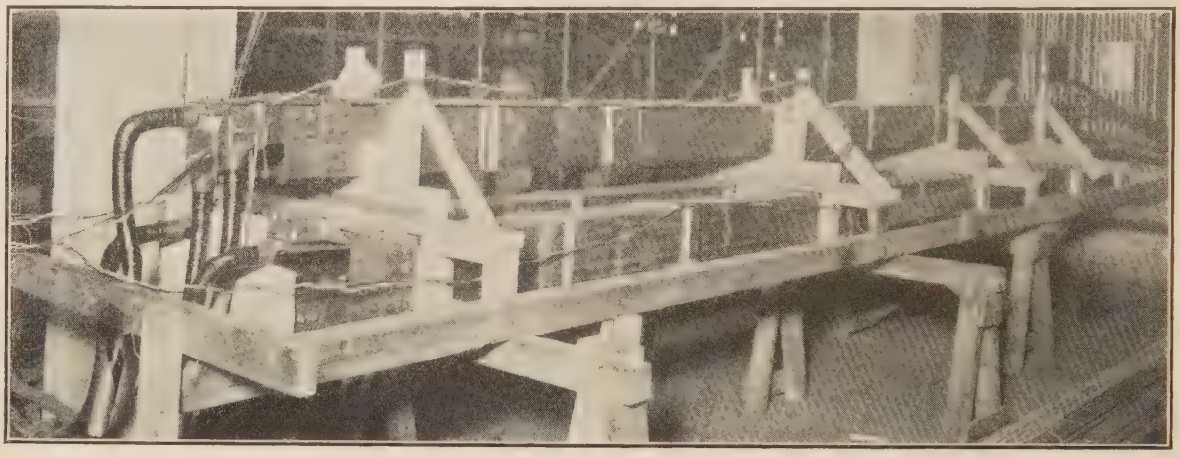

Fig. 1—Test Bus

Consisting of four 8-in. by ¼-in. copper bars per phase, arranged in rectangular form. Phases on corners of an equilateral triangle, 17-in. sides.

Temperature measurements were made by means of thermocouples connected to the centers of the various bars in this 20-ft. section. A number of checks were made during the progress of the test with temperature measurements at points other than the center of the bus to be sure that no contact resistance or other variables were affecting the results. Impedance voltage drop was measured by means of straight leads perpendicular to the bus, carried far enough away to be out of the influence of the magnetic circuit.

In addition to these measurements, the current in various parts of individual conductors was also determined by a method similar to that described by C. F. Wagner.[4] The leads described running parallel to the bars, were No. 24 enameled wire. In order to be positive that there was no space between the wire and the bus surface and no sag, this wire was cemented to the surface of the copper with asbestos cement. To eliminate end effects, only the central 15 ft. of bus were used. In the lower right-hand corner of Fig. 1 may be seen a four-inch bar with five leads cemented on.

We have found a number of things which enter into the construction of a bus that are not constant for all circuits. For example, the current distribution will be very different on single-phase from that on three-phase circuits. Also, there is an extremely great difference between isolated-phase and group-phase busses due to proximity effect.

The majority of engineers are not particularly interested in the exact distribution of current in various parts of the bus. The primary question which enters the designer's mind is rather how much copper he must use and how he may best use it. A concrete example of the distribution of current will, however, clarify ideas of the results of skin effect and proximity effect and help a great deal in deciding for a particular case what form should be used. In Fig. 2 is shown a three-phase bus,

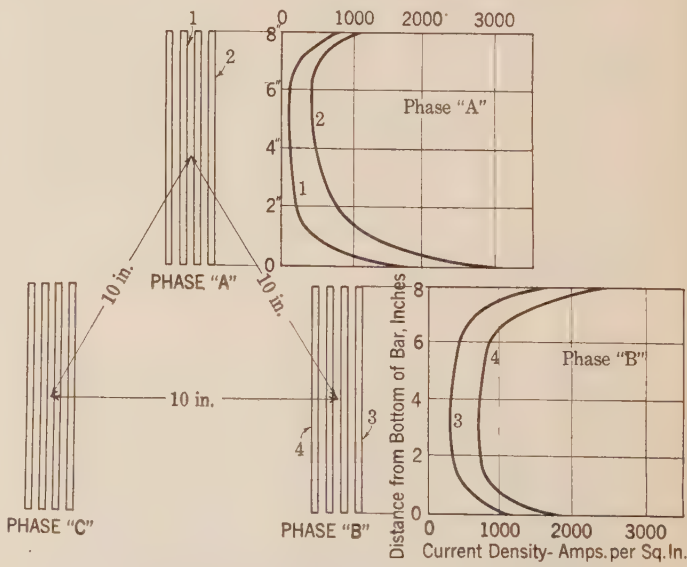

Fig. 2—Current Distribution in a Three-Phase Bus

Consisting of four 8-in. by ¼-in. copper bars per phase, at 4000 amperes per phase.

each phase consisting of four 8-in. by ¼-in. bars per phase with phases set in an equilateral triangle on ten-inch centers. It will be noted that the current in *A* phase bus is practically all in the very bottom edge of the bars, and the usefulness of the upper half of the bar is more in the nature of a radiator than a conductor. For this

4. "Current Distribution in Multi-conductor, Single-Phase Busses," C. F. Wagner, *Electrical World*, March 18, 1922.

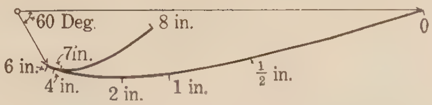

Fig. 3—Polar Diagram of Current Distribution in Outer Surface of 8-In. by ¼-In. Bar

Figures refer to distances from bottom edge of bar The surface considered is the same as Curve 2 in Fig. 2.

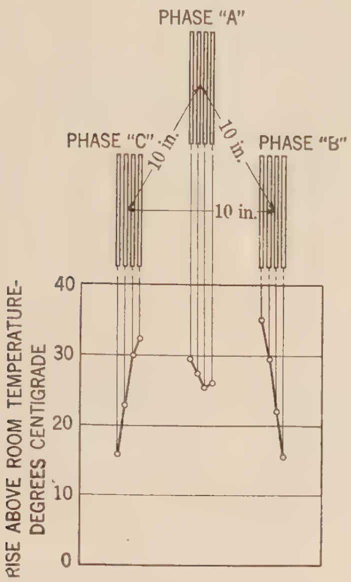

Fig. 4—Temperature Rise on a Three-Phase Bus

Consisting of four 8-in. by ¼-in. bars per phase under a continuous load of 4000 amperes per phase. Bus mounted in still air and not enclosed.

reason a bus of similar construction, except made of four-inch bars in the same layout, that is, four bars wide and two bars high, would not be nearly so effective because the upper set of bars would not carry much

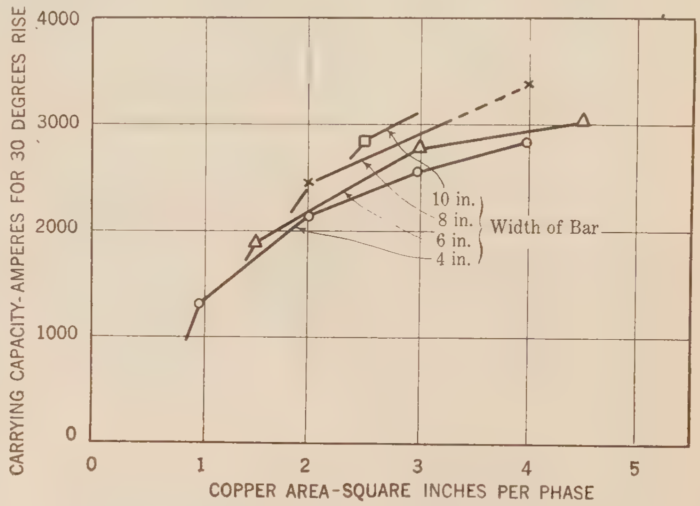

Fig. 5—Electric Power Club Standards

Ratings of laminated busses on grouped phases up to 3000 amperes at 60 cycles. Centers on a straight line with 8 in. between phases; ¼-in. spacing between laminations.

current, and in addition would have poor heat connection to the lower bars. Hence, they would not serve as good radiators.

It may also be interesting to note in Fig. 3 the relation of the phase angle of current in various parts of the bar.

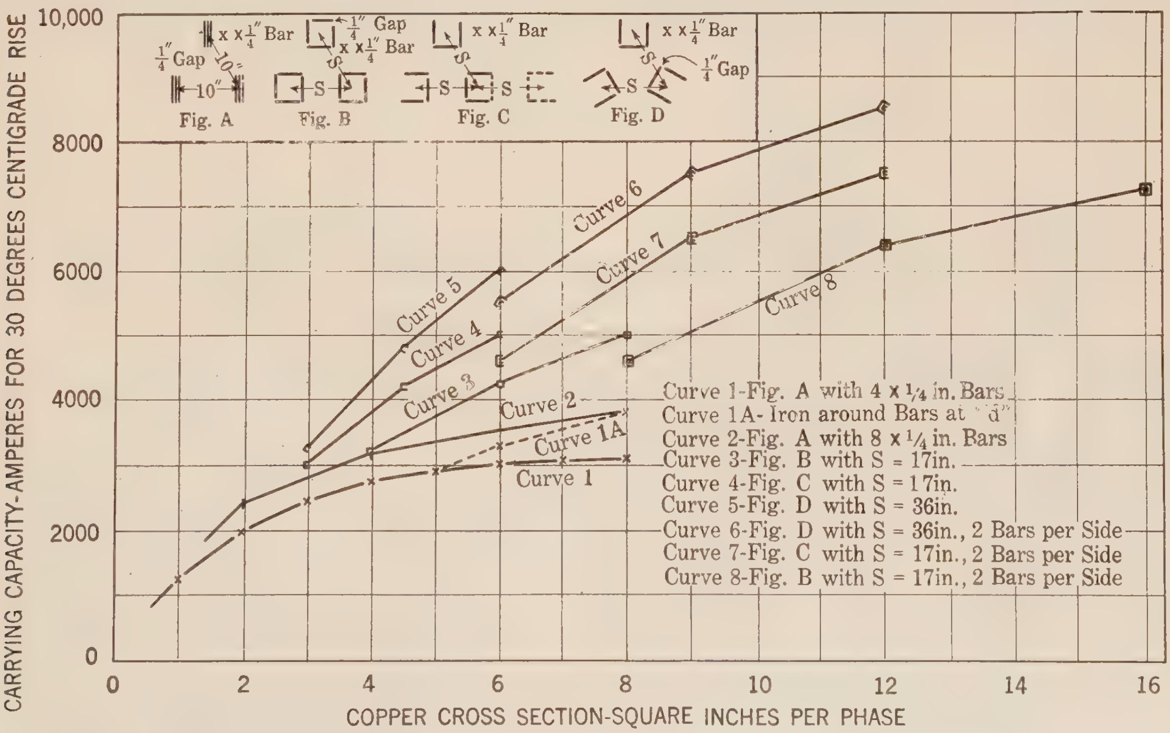

Fig. 6—Ratings of Busses on Grouped Phases Above 3000 Amperes at 60 Cycles

All bars are ¼ in. thick by 4 in., 6 in. or 8 in. wide. For instance, the center point on Curve 6 represents six bars of 6-in. by ¼-in. copper and the upper point on the same curve means six bars of 8-in. by ¼-in. copper.

It will be seen that the current at the minimum point lags 60 deg. behind that in the lower edge and that the point of minimum current is 6 in. instead of 4 in. from the bottom of the bar. As we go nearer to the center of the bus, the current lags further behind that in the outer edge of the outer conductor until we find the current at the center is very nearly 180 deg. out of phase. As a striking example, in a bus consisting of four bars laid on the sides of a rectangle, the addition of a fifth bar in the center actually increased the losses and temperature rise for the same current. In Mr. Wagner's article,[4] for single-phase busses he draws the curve from the outer edge to the center of the bar, and assumes that the same condition holds from the center to the opposite edge of a bar. This is perfectly true in some cases but not at all true in others, and the electrical center, or the point of minimum current in a bar, may not be the physical center.

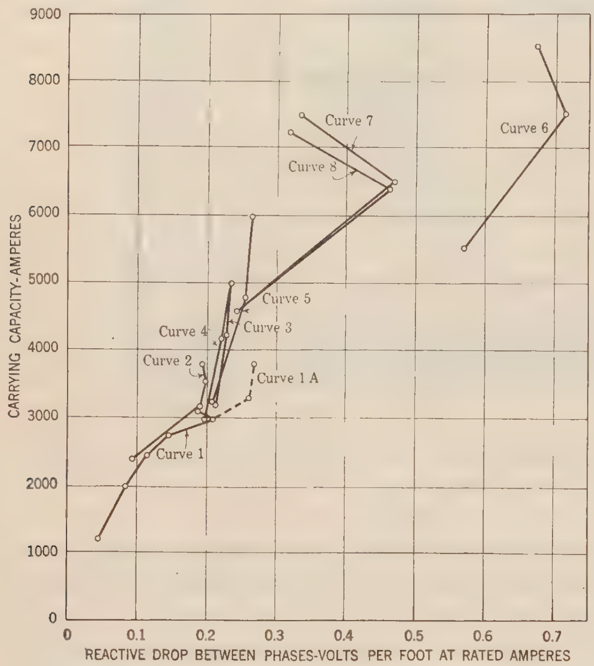

Fig. 7—Reactive Voltage Drop on Three-Phase Busses

Curve numbers and points refer to corresponding curve numbers and points for busses shown in Fig. 6. With phases arranged with centers on the same straight line, the average drop will be about 25 per cent higher and the drop in the two outer phases will be higher than that in the center phase.

If we now look at Fig. 4 to get the temperature rises of the various bars and consider that the temperature rise is proportional to the square of the current, we get a somewhat erroneous impression, due to the fact that while the central bars may be carrying some current, this is not a measure of their effectiveness, because as stated before the current in the central bar may be sufficiently out of phase to be of little or no value.

For moderate currents the important item in the design of a bus is the matter of ventilation. When we come to consider very heavy currents, this matter of ventilation is of minor importance, since ventilation is useless if all the current is carried in a small portion of the bus. The prime consideration, then, is to put the copper where it will be most useful.

Bus Capacities

There are very few data available at this time on the carrying capacity of busses for heavy current. For example, some operating companies have for many years used the standard of 1000 amperes per square inch of copper section. This gives ample copper for busses up to 2000 amperes, but beyond this point the rule no longer holds. For isolated phases, the General Electric

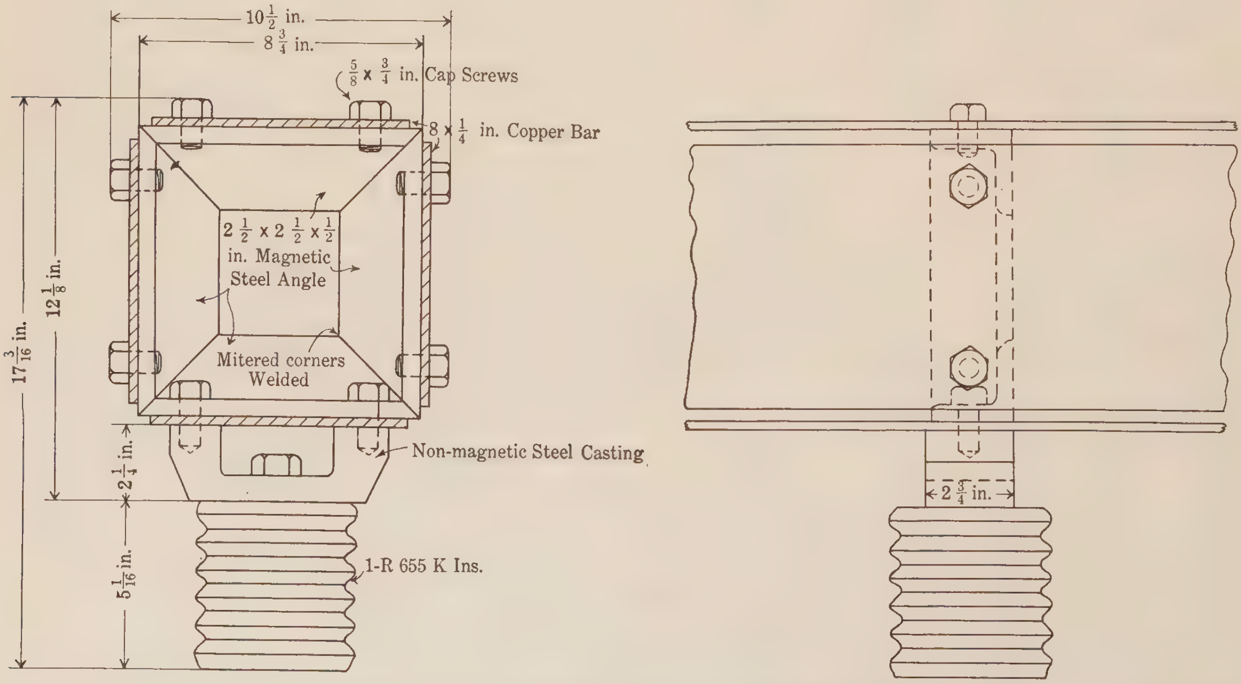

Fig. 8—Form of Bus Support for Rectangular Busses Requiring Drilling of Copper on Job. No Clamps Required

Company has worked out a system of busses[5] which is not at all difficult to mount and is very satisfactory for currents up to 7400 amperes at 60 cycles. Due to the proximity effect as shown in the test data, it is obvious that this type of bus construction would be of little value for group phases on very close centers since the current would all be thrown into one corner of the bus and would cause it to run very hot. The Electric Power Club has given as a standard Fig. 5, which is for group phases up to 3000 amperes. Beyond this point we have compiled from our test data the curves in Fig. 6 for special types of bus construction. The curves do not, of course, give all the data required for any particular installation, but they give the points necessary for determining what should be used.

In Fig. 6, Curve 7 gives the rating of C on 17-in. centers. If the phases are separated further, the ratings of these busses will be raised somewhat but not so high as Curve 6. Curve 6 gives the rating of D on 36-in. centers, and the rating of this bus would be lower on the closer centers but not so low as Curve 7. In Curve 8 the rating may be very materially increased by one or both of two methods, either by a wider opening of the corners of the rectangle, or by further separating the phases. If both these things are done, we may obtain a bus of perhaps higher carrying capacity than that given in Curve 6. When the space limitations or the allowable reactive drop does not demand that phases be on the corners of an equilateral triangle, the dotted arrangement shown in C is practically equivalent in carrying capacity to that of D.

5. *General Electric Bulletin No. 87000-D*, Sept. 1924, p. 26.

Up to about 3000 amperes the reactance of the bus is not of very great importance, but beyond this point and especially for low voltages it becomes quite a serious item. For instance, on a bus carrying 6000 amperes at 230 volts and only 30 ft. long, it may be readily seen from Fig. 7 that the reactive drop may be from 3 per cent to 8 per cent of line voltage. This, in addition to the reactance of feeders, may cause a very poor voltage regulation at low power factors unless care is used in the selection of the bus.

Another important point in the matter of reactance is that it is frequently necessary to parallel transformer banks of different sizes or with different lengths of copper from the banks to the point of paralleling. For large transformers the bus reactance is considerable compared to the transformer reactance and up to the point of paralleling, the bus reactance may be considered a part of the transformer reactance so far as division of load is concerned. This effect is especially noticeable where transformer banks of different capacities are paralleled, because the percentage reactance per foot is very much higher for large than for small busses. Sometimes it even becomes necessary to install a reactance in series with the smaller transformer bank to prevent overheating of one bank when the other is not fully loaded.

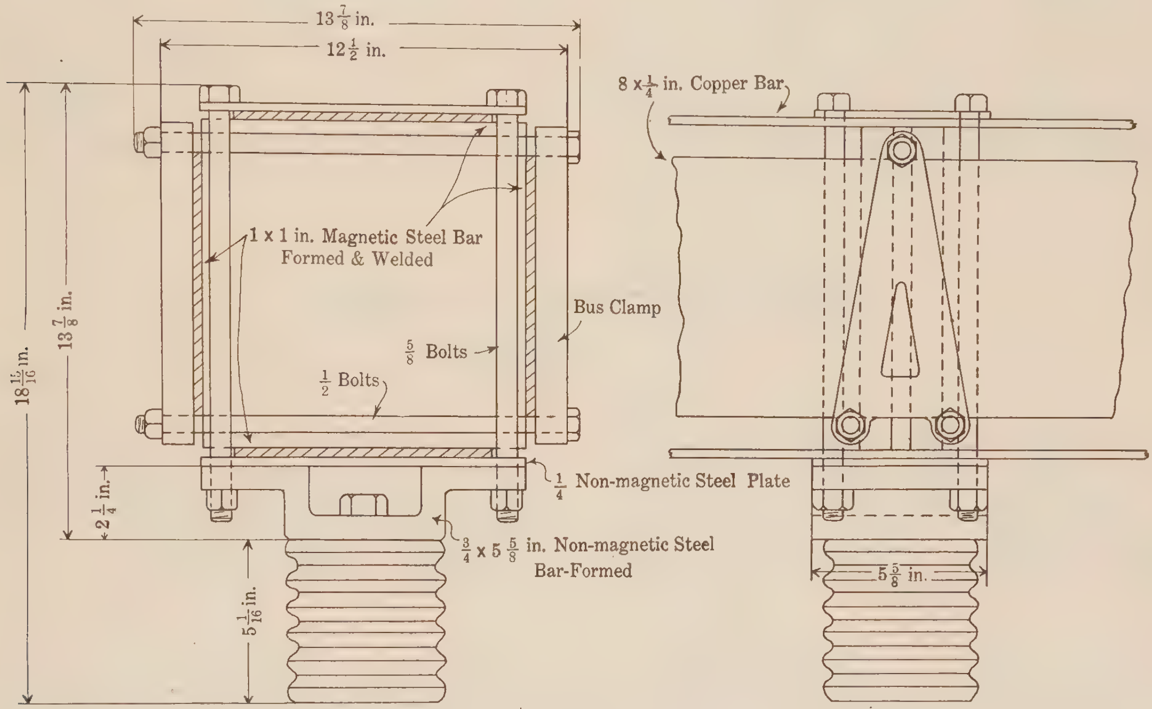

Fig. 9—Form of Bus Support for Rectangular Busses Requiring No Job Drilling of Copper

In Curve 1-A, Fig. 6, is shown the carrying capacity of a laminated bus, balanced with magnetic steel, as proposed by Mr. Wagner. It is true that the addition of this magnetic steel does increase the carrying capacity. However, the amount of iron to be added must be determined by the cut-and-try method for any in-

stallation and the cost of adding this balancing becomes prohibitive, especially when the class of labor usually employed knows nothing of what is to be done.

The principal objection to the use of a rectangular form of bus is the same as one of the objections to the tubular form of bus; that is, the difficulty of mounting. However, a little careful consideration will show that the rectangular bus is not particularly difficult to mount since flat clamps may be used which are very similar to those used for an ordinary laminated bus.

The manner of making taps is little more difficult than with the ordinary laminated bus because all the copper surfaces are flat. Especially is this true if the corners of the rectangle are left open, making room to handle bolts inside. The necessary bracing between phases may be attached to the clamps in practically the same way as is done with laminated busses. We have added two preliminary sketches of supports, (Figs. 8 and 9). The type which is cheapest to use depends a good deal upon the type of labor employed. Where skilled and experienced labor is used on the job, Fig. 8 requires less material and would probably be cheapest to install. Where the labor is not particularly skilled or fast, or where labor costs are high, Fig. 9, although it requires more material, takes very little time to mount and would not be as expensive per ampere of current carried as the clamp now used for laminated busses. Neither one of these supports is particularly difficult to handle, nor is it particularly difficult to make taps to this bus since there is room for strap copper or lug connections on the surface of every bar. When these supports are used on the form of bus shown in Fig. 6c, the bar nearest the support may be omitted without changing the method of mounting.

In presenting this paper we have hoped to give a ready reference through which engineers may choose the type of bus best adapted for their needs without any involved calculations which they have neither time nor inclination to make. In conclusion, let us state that although the Electric Power Club Standards call for the maximum of 30 deg. cent. temperature rise and the busses given are designed on this basis, nevertheless, a number of years' experience has shown that a 40-deg. temperature rise gives no trouble due to oxidation when reasonably good connections are made. Especially is this true when the ambient temperature is nearer to 25 deg. than to 40 deg. cent.

Motor Band Losses

BY T. SPOONER[1]

Member, A. I. E. E.

Synopsis.—*It is shown that railway motor band losses are of appreciable magnitude, sometimes sufficiently large to be detrimental to the cooling of the machine. By tests of a small machine checked against those of a large one, the band losses are found to vary according to the 1.7 power of the frequency and from the 1.35 to the 1.8 power of the induction, depending on the width and type of band. These losses are shown to be due chiefly to the change in the radial component of the flux as the band passes by the pole tip. For average bands, about 15 per cent of the losses (hysteresis and eddy) are due to the tangential flux in the bands. A typical set of curves is shown for calculating band losses.*

* * * * *

In most types of rotating electrical apparatus, the rotor windings are held in position by some sort of slot wedge. However, in the case of d-c. railway motors, it is almost universal practise, (in this country at least), to hold the rotor windings in the slot by means of wire bands. These bands, when over the core material, are placed in shallow slots in the core. They are from ½ in. to ¾ in. wide and are spaced approximately three in. apart. Much wider bands are often used over the end windings but in this paper we shall be concerned only with the bands over the core.

It is often assumed that the band losses are so small as to be negligible; and even if they are not negligible, the heat is readily dissipated, since the bands are on the surface of the rotor. As a matter of fact, band losses are sometimes of quite considerable magnitude and they occur adjacent to the windings, thus preventing loss of heat from the windings and teeth, even though they do not actually transfer heat to these parts. Moreover, the band losses may materially heat the cooling air in the air-gap, thus making it much less effective.

Band Construction

There are many kinds of band construction and band materials in use, but here we shall deal with only three or four common types. The steel banding wire for the experiments to be described had a diameter of either 0.0453 in. or 0.0641 in., and a resistivity of about 18.5 microhm-centimeters. The bands were wound on a 0.0125-in. soft iron, tinned strip which, in turn, was insulated from the core by means of a strip of asbestos tape. In order to reduce the band losses, in some cases each band was divided into two sections, each section having its own strip and the two sections insulated from each other. The wires of each band or

1. Research Engr., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

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section were held together by clips of 0.0125-in. soft iron about ½ in. wide, spaced approximately every three inches. The wires were wound on the armature under considerable tension and the wires, strips and clips were soldered together. The solder was of pure tin, having a resistivity of about 13 microhm-centimeters.

Factors Affecting the Band Losses

The problem of band losses is much more complicated than is evident from a first inspection. So far as the phenomena have been analyzed, the following factors enter into the problem:

a. Width of bands
b. Width of teeth at air-gap
c. Size of band wires
d. Amount of solder used
e. Dimensions of tinned strips and clips
f. Normal resistivity of wire, solder and tinned strips
g. Temperature of bands
h. Frequency
i. Induction
  1. Tooth (radial)
  2. Band (tangential)
j. Field form
k. Air-gap
l. Depth of band groove

If the bands are not insulated from the core, the losses due to the bands may be anywhere from the insulated values to many hundred per cent higher, the values depending on the intimacy of contact between the bands and laminations. The following discussion assumes perfect insulation from the teeth.

There are several types of band loss for a given total armature flux which may be classified as follows:

1. Eddy-current losses in band wires, solder and tinned strip, due to radial flux.

2. Eddy-current losses in band wires, solder and tinned strip due to tangential flux.

3. Normal hysteresis loss in band wires and strip due to tangential flux.

4. Additional hysteresis losses due to displaced hysteresis loops.

5. Additional armature tooth loss (eddy-current) due to the damping out of flux by the bands in the region of the pole tips, thus producing flux across laminations which may result in extra eddy losses.

The eddy-current losses which occur in the bands themselves, due to item 1, (radial flux), are by far the most important, as can be shown by a few simple calculations from data available. The induced voltage in the bands has much the same wave form as given by the familiar case of an exploring coil surrounding a tooth and connected to an oscillograph. It has, in general, two large positive humps, followed by two large negative humps, with many intervening ripples. The large humps are produced when the tooth passes a pole tip and their shape and magnitude are a function of the shape of the pole tips.

The tangential fluxes passing from one pole tip to the next, through the bands, are usually of much higher flux density than the radial fluxes, but due to the small thickness of the bands, the eddy-current losses are small. However, the hysteresis losses correspond to the tangential flux; namely, the maximum induction.

The bands are subjected to an elliptical field and we shall assume that the hysteresis loss is the same as would be produced by the maximum tangential induction acting under alternating flux conditions. This tangential flux is a maximum in the position just before the band passes under the pole tip. It is lower at a position midway between the poles and zero at the center of the pole. This decrease in flux at the mid-point between the poles produces a minor hysteresis loop. Since this loop is greatly displaced from the normal position, there results appreciable increase in the hysteresis losses.

Due to the eddy currents in the bands, caused by the radial flux and the consequent damping out of the flux through the bands, the air-gap flux must tend to pass around the bands, giving decreased relative induction in that portion of the tooth under the bands. These fluxes tend to become uniform again under the bands, thus producing a flux component at right angles to the plane of laminations which may produce appreciable eddy-current losses.

Test Apparatus

The test results to be described were obtained chiefly on a typical small four-pole railway motor direct-coupled to a d-c. shunt motor. Two armatures were provided with the following dimensions:

	Armature A.	Armature B.
Diameter	9 in.	9 in.
Length	7 "	7 "
Number of slots (open)	31	16
Slot width at air-gap	0.370 in.	0.635 in.
Slot pitch at air-gap	0.911 "	1.77 "
Slot depth	1.00 "	1.50 "

The armatures had three band grooves 0.125 in. deep and 0.75 in. wide. The motor was provided with two sets of poles, one normal and the other chamfered 1/16 in. at each tip. The bands consisted of fourteen turns each of 0.0453 in. wire or eight turns each of 0.0641 in. wire. Both single and double bands were used for the larger size of wire. In the case of the double bands, each section had four turns.

Test Methods

Tests were made with three air-gaps; namely, 0.1 in., 0.2 in. and 0.3 in. and three speeds; 600, 1200 and 1800 rev. per min., corresponding to 20, 40 and 60 cycles respectively. Chamfered poles were used with 0.0452 in. and 0.0641 in. bands and 0.1 in. air-gap only.

The d-c. drive motor was supplied by a storage battery. No-load losses were determined with the bare armature for the various air-gaps and for various field excitations. The armature flux-per-pole was determined for various excitations by means of an exploring coil and d-c. voltmeter connected through a synchronous contactor. Corresponding maximum armature tooth inductions were determined ballistically by means of a tooth exploring coil and a ballistic galvanometer. Also the r. m. s. tooth voltages were determined by means of the tooth exploring coil and a Paul dynamometer type voltmeter which had a very small frequency error. From a previous investigation, data were available for the actual tooth-voltage wave forms as obtained by oscillograph.

In order to determine the tangential inductions in the bands the exploring coil was wound on the center band between two teeth. The motor field was reversed and the band inductions obtained ballistically. This was done for various field strengths for the position opposite the center point between the poles and for the position of maximum tangential induction, namely, with the exploring coil a little beyond the tip of the pole. Also a curve was obtained for one field strength and the various air-gaps between tangential band induction and armature position for a rotation of 90 electrical degrees.

Test Results

While the test results are referred to the average tooth-top induction, since this factor probably correlates best with the band losses, it should be remembered that the actual radial band inductions are considerably less and sometimes only about one-half the values corresponding to the average tooth top induction, due to the greater reluctance produced by the band grooves.

Fig. 1 shows some typical curves for tangential band inductions, which inductions are chiefly responsible for the hysteresis losses. The radial flux is, of course, approximately proportional to the tooth-top inductions and has nearly the shape of the field form. Fig. 2 shows some typical band-loss data for armature *A*, with the armature core, tooth and pole-face losses included for comparison. It will be noted that in one case the tinned strip was omitted from under the band wires.

Fig. 3, plotted on double log paper, shows band-loss calculation curves for a 0.0461-in. insulated band, eight wires wide. This method of plotting makes a very convenient form in which to have the results, since the losses vary approximately exponentially with frequency and induction. From theoretical and somewhat meager test considerations the band losses apparently vary about as the square of the band width. If desired, another curve could be added to Fig. 3, giving a factor to take care of the width.

It was found that the band losses varied only slightly with air-gap for a given armature flux, due probably to the fact that with larger air-gaps, though the radial flux increased, the rate of flux change became less, thus giving a relatively smaller induced band voltage. Also pole chamfering had only a small effect due to the fact that while the maximum individual voltages were less, the maximum tooth inductions were greater for the same total pole flux.

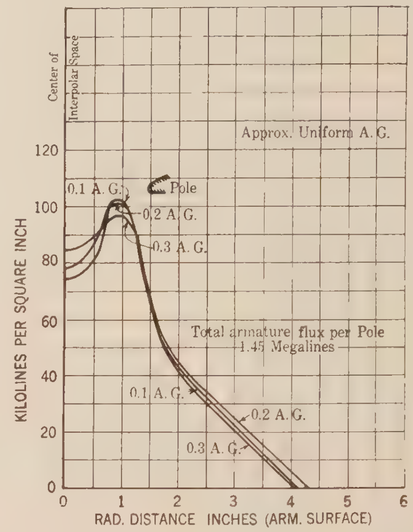

Fig. 1—Tangential Band Inductions—0.0641 Bands

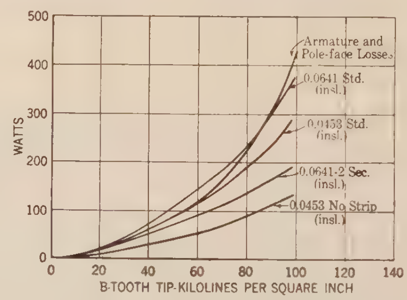

Fig. 2—Band Losses for D-C. Railway-Motor Armature "A" 0.2 Air Gap—1200 Rev. per Min.

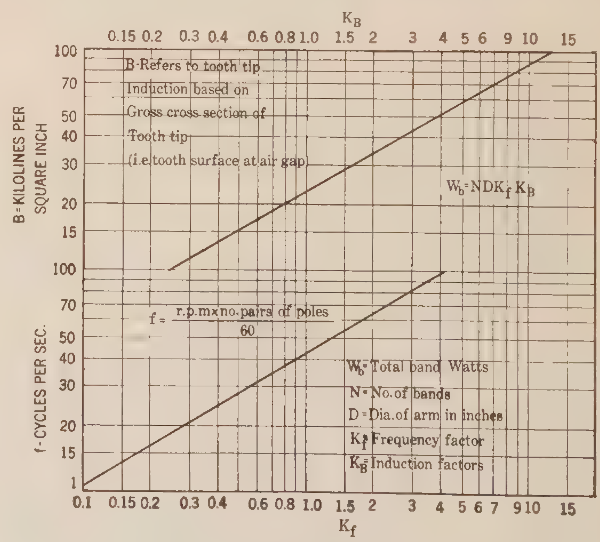

Fig. 3—Band Losses for D-C. Railway-Motor Armature 8-0.0453 in. Diameter Wires— One Sec. Strip

The following table gives the band loss coefficients, tooth-induction and frequency exponents for the *A* armature.

TABLE I

BAND LOSS COEFFICIENTS AND EXPONENTS

Coefficients are for 1200 rev. per min. (40 cycles), 80 kilolines tooth tip induction, and 0.1 in. air-gap.

Band (Diameter of wires-in.)	Coefficient	Exponents Frequency	Tooth Induction	Remarks
0.0453 in.	71	1.71	1.52	No strip
0.0453 in.	230	1.71	1.63	Strip
0.0641 in.	238	1.67	1.73	Strip—one sec.
0.0641 in.	188	1.85	1.87	Strip—ch. poles
0.0641 in.	180	1.68	1.34	Strip—two sec.

The coefficients are the total losses due to the presence of the bands for the specified conditions. There is some variation in exponents and coefficients for various air-gaps and frequencies. The values given are the mean results for the exponents. Tests on a much larger machine gave approximately the same results.

In order to show the relation between the various band losses, the hysteresis losses due to the tangential fluxes were calculated for certain conditions as follows: 0.0641 in. bands (one section), 60 cycles, 80 kilolines/sq. in. tooth-top induction and 0.2 in. air-gap.

Tangential eddy current loss	= 43	watts
Hysteresis loss	= 23	watts
Sum	= 66	watts
Actual test loss	= 470	watts.

This indicates that for these conditions 85 per cent of the loss is due to the radial flux.

It would normally be assumed that wider teeth would produce higher band losses. Tests obtained with the *B* armature, however, having only 16 as against 31 teeth and correspondingly wider tooth tops, gave approximately the same band losses. By means of a ballistic exploration of the tooth-top inductions over the leading and trailing portions of the teeth as they passed by the pole tips, it was found that most of the change in flux as a point on the tooth top passed the pole tip occurred over a distance equal to less than one-half the tangential width of the tooth top for the *B* armature. This means that for these particular poles a tooth top width of from 0.5 to 1 inch or over will give approximately the same band losses. For still narrower teeth there might be considerable difference.

Some tests made on the experimental and other machines show that if the bands are not insulated from the core, very much larger losses than normal will occur. The armature laminations are short circuited on the shaft and the bands touching the laminations at the periphery complete an electrical circuit, which may make a very good path for induced currents. It was found possible to produce losses of several kilowatts in the small 7 x 9 armature by this means. It is possible to apply uninsulated bands without producing these extra losses but only in the case that the slot windings are so thick radially that the bands do not touch the core. In practise, this procedure is not possible and there is a general tendency toward the use of insulating materials even though most of the band tension is carried by the coils.

Discussion of Results and Conclusions

The eddy currents in the bands due to the radial flux which are chiefly responsible for the band losses are undoubtedly of sufficient magnitude to appreciably hinder the change of flux as the band passes under the pole tip. This is analogous to skin effect. It will be noted that at low and moderate inductions, the two-section bands have nearly as much loss as the wide single-section bands, although theoretically the losses for the former should be ¼. This is probably due partly to the fact that the losses for the wide bands are reduced by skin effect at the lower inductions. At the higher inductions, the magnetizing forces become so great that the damping effect of the eddies becomes less important and relatively more radial flux passes through the wide bands, thus giving a higher induction exponent for the wide bands than for the narrow. Again due to these damping currents, flux may pass around the bands under certain conditions, thus altering the eddy-current losses in the teeth by producing flux components at right angles to the tooth laminations. This is purely speculative. These induction exponents are lower than would be expected. It may be that heating of the bands has much to do with it.

The frequency exponents are less than two, due, undoubtedly, partly at least, to the skin effect in the bands.

It has been impracticable so far to derive a theoretical mathematical formula for calculating the band losses caused by the radial component of flux. This is an interesting problem for anyone mathematically inclined. The chief difficulty, even without assuming any damping effects, is to determine the most probable path of the eddy currents in the bands.

Considerable reduction in band losses may be effected by omitting the metal strip under the wires, but this gives less satisfactory construction from a mechanical standpoint. The insulation under the bands can not be dispensed with safely in all cases.

Non-magnetic band wire may be used if desired, but due to its inferior mechanical properties and slight effect on the band losses, its use is probably not justified.

A band wire and a solder of high electrical resistance would be of considerable advantage if they were otherwise suitable.

In large railway motors, the band losses may, under certain conditions, amount to two or three kilowatts and are therefore not negligible. Band temperatures up to 200 deg. cent., or more, may occur. At very high inductions the band temperature may increase so rapidly that the rate of increase of band losses with induction will sometimes decrease very considerably due to the increased resistance of the bands.

A New Edition of A. I. E. E. Standards

BY F. D. NEWBURY[1]

Fellow, A. I. E. E.

Editor's Note. The following article was prepared by Mr. Newbury in July and was first published in the September issue of *The Electric Journal*. It has been revised in some minor respects to bring it up to date and is published here in order to extend the knowledge of the new Institute Standards to a still wider circle of engineers.

THE American Institute of Electrical Engineers is now issuing a new edition of its Standards that involves a complete change in form of publication and many important changes and additions in subject matter. This is an event of importance to the electrical industry and engineers generally should become familiar with these new Standards. The purpose of this brief article is to bring the subject to the attention of engineers and point out some of the major changes that have been made.

Since the first publication of Institute Standards, more than twenty-five years ago, there have been only two other revisions that compare with the present one in scope and importance. In December, 1914, a complete revision was published which had been initiated by the extensive program of papers presented at the first Midwinter Convention in February 1913. This first revision was notable for the new material it introduced: the hot spot principle in determining limiting temperature rises; the classification of insulations according to safe temperature limits; the single 50 deg. rating without overload for rotating machines and the use of the embedded temperature detector method of measuring temperatures in large alternators. This revision definitely extended the scope of the Standards to include other types of apparatus than rotating machines and transformers, with which the earlier editions had been principally concerned.

The second major revision appeared in 1921. The Standards were completely revised in form and arrangement but only minor changes in substance and additions of new sections were made. This change in form consisted of the separation of the Standards into chapters containing general material applying to all types of machines, and apparatus, and chapters containing specific material applying to a particular type of apparatus. There were three of these general chapters; one on General Principles on which the Standards are based, a second on General Rules (applying to all types of apparatus), and a third on General Definitions. These general chapters were followed by thirteen chapters, each dealing with a specific type of apparatus or a specific branch of the electrical art, as, for example, rotating machines, transformers, control apparatus, wires and cables, etc.

It is perhaps worthy of note that two of the three major revisions (the third being the present one) have followed an extensive reorganization of the Standards Committee, itself.

The 1914 revision was carried out by the committee appointed August 1, 1913, which was considerably enlarged in order to permit the formation of subcommittees to care for various parts of the work. Six subcommittees were appointed to deal with such subjects as rating, (with particular reference to machines and transformers), telegraph and telephone standards, railway standards, nomenclature and symbols, wires and cables, and control apparatus. This was the first recognition, in the organization of the Standards Committee, of a major interest in Standards other than machines and transformers. Permanent subcommittees, each responsible for a part of its work, were a feature of the Standards Committee organization from that time to 1922. With the gradual increase in the scope of the Standards Committee's interests, the membership grew until in 1921-22 there were 37 members. The organization of the American Engineering Standards Committee and the increasing interest of other societies in standardization brought up many problems of policy and procedure. The consideration of these questions necessitated frequent meetings and an experienced membership familiar with the increasing complexity of organization relationships and the policies involved.

To meet these new conditions, the Standards Committee was completely reorganized by the Board of Directors of the Institute and the Committee appointed August 1, 1922, centers about a small executive committee which meets monthly or more frequently, if necessary. The formulation of Standards is entrusted to representative working committees. Each working committee is appointed for a specific task, and is discharged when that task is completed. Non-members of the Institute may be appointed on Working Committees.

Since this reorganization in 1922, thirty-nine working committees have been appointed and several hundred engineers have been actively connected with the preparation of Standards. But the regular business of directing the work has been in the hands of the small executive committee of from ten to 15 members. The Standards Committee consists of the Executive Committee, all the chairmen of active working committees and various Institute representatives on other standard-

1. Manager, Power Eng. Dept., Westinghouse E. & M. Co. Member Executive Committee, A. I. E. E. Standards Committee.

izing committees. This is a fluctuating membership and has included as many as fifty members. The principal function of the Standards Committee is to vote on the adoption of Standards completed by working committees. Thus, there are three elements in the complete organization: a small executive committee to direct the work, a flexible organization of working committees to formulate standards, expanding and contracting with the volume of work to be done, and a relatively large Standards Committee of experienced members to pass on a standard before it is approved. This form of organization has met the requirements successfully during the past three years, and, so far as can be seen at the present time, will continue to function successfully under conditions as they may be anticipated to develop in the future.

It was believed when the 1921 edition was approved that the new arrangement of the Standards would facilitate their use and make it possible to readily make changes and additions as they became necessary. Experience, however, soon developed certain defects in this edition that completely overshadowed these expected advantages.

The separation and amplification of the material in the chapter on General Principles gave this theoretical groundwork of the Standards an undue importance. The standard figures for total hottest spot temperature limits and the conventional allowances (the assumed temperature differences between hottest spot temperatures and observable temperatures) were applied too rigorously. The principle, for simplicity's sake, assumed a single value of conventional allowance for a given method of temperature measurement; actually this temperature difference varies with the total temperature, the kind of insulation and the type and dimensions of the construction employed. Many conflicts arose in determining limiting temperature rises; the rigid application led to one figure while practical experience led to a different figure. These experiences developed a strong sentiment in favor of making the application of the principle of hottest spot temperatures less rigid in arriving at practical working standards.

It was also found that the new arrangement of material adopted in the 1921 Edition of the Standards made the Standards actually less convenient in their every-day use. The material relating to any specific type of apparatus—and this was particularly true in the case of rotating machines and transformers—was separated and the user of the Standards might have to look in three different chapters for the information he sought. A strong feeling developed that the material for each major class of machinery or apparatus should be collected in one place. Engineers interested in transformers, for example, prefer a single inclusive chapter on transformer standards rather than one chapter for certain general definitions, such as Classes of Insulation, another chapter for other general definitions of interest to transformer engineers, still another chapter for certain temperature limits and other rules of general application, and a fourth chapter for other temperature limits and other specific transformer standards.

The increasing scope of electrical standards and the increasing number of technical and commercial organizations interested in the subject has gradually developed the necessity of dividing the single book of A. I. E. E. Standards into a sufficient number of separate sections or pamphlets, so that the Standards for each major type of machinery or apparatus could be printed as a separate pamphlet that would be, as far as practicable, complete in itself, and could be revised without reference to any other Institute Standard. This separation of the complete body of Institute Standards into a number of separate publications had advantages, not only from the standpoint of time of revision, but also from the standpoint of the different organizations interested in different standards. There are a large number of organizations interested in one or more subjects dealt with in the A. I. E. E. Standards, but no other organization is interested in the whole body of A. I. E. E. Standards.

A final criticism of the 1921 Edition concerns the grouping of standards relating to rating and testing with standards and recommendations relating to safe operation under service conditions. The distinction between a standard test rating and permissible outputs under various conditions met with in service may require explanation and illustration. A standard "test rating" of a machine is based on its capacity under certain standardized test conditions. These are relatively simple and capable of exact definition as is required by their purpose. Two of the most important test conditions are cooling air temperature and altitude. The standard test conditions are intended to be the same as the corresponding conditions usually found in service, but the test conditions are few in number and limited in range while service conditions are infinite in variety and in combination, and vary widely in numerical values. Thus, according to the Institute Standards, tests to determine the test rating shall be made with the cooling air temperature between the limits of 10 deg. and 40 deg. and at an altitude between the limits of sea level and 1000 meters. These are "standard test conditions" and likewise "usual operating conditions." But users of electrical apparatus are interested in the outputs that can be taken safely from apparatus at various air temperatures and altitudes within and beyond the limits of standard test conditions and under other than normal conditions of voltage, frequency, power factor, etc. This has led to the demand for rules or recommendation for "operating recommendations" for conditions of service other than standard test conditions. As a simple example of this distinction between rating under standard test conditions and permissible output under various conditions encountered in service, consider a

motor having a "test rating' of 10 h. p. This is the usual nameplate rating. The same motor may also have the following permissible outputs under the given conditions:

8.5 h. p. at 50 deg. air temperature and 1000 meters altitude
8 h. p. at 4000 deg. meters altitude and 40 deg. air temperature
11.5 h. p. at 25 deg. air temperature and 1000 meters altitude
10 h. p. at 25 deg. air temperature and 2500 meters altitude

These numerical values are illustrative only; no official action has been taken to standardize such values.

There still exists some mixture of rules for rating and testing under standard test conditions and rules or recommendations for operation under service conditions in the new revision of the Institute Standards, but this edition has been greatly improved in this respect. A great deal of confusion has existed, and, to a degree, still exists in the rating situation because of a failure to distinguish clearly between a test rating, established for purposes of comparison between machines or equipment or between equipment and specifications, and the actual loading of machines and apparatus in service. Engineers, interested in the further development of electrical standards are working on this problem, and a Working Committee of the Standards Committee has been appointed to study the problem of formulating rules or recommendations concerning the performance of apparatus under service conditions.

In the new edition of the Standards, there will be, when it is completed, more than forty separate sections or pamphlets, each dealing with one major type of machinery or apparatus. Any combination of these sections can be supplied in a loose-leaf binder to suit the interests of any engineer. The following lists give those sections that are completed and those that are in an advanced stage of preparation:

Available Adopted Sections.

No. 1. (April 1925) General Principles upon Which Temperature Limits are Based in the Rating of Electrical Machinery.
5. (July 1925) Standards for Direct-Current Generators and Motors and Direct-Current Commutator Machines in General.
7. (July 1925) Standards for Alternators, Synchronous Motors and Synchronous Machines in General.
8. (March 1925) Standards for Synchronous Converters.
10. (July 1925) Standards for Direct-Current and Alternating-Current Fractional Horse-Power Motors.
11. (July 1925) Standards for Railway Motors.
13. (August 1925) Standards for Transformers, Induction Regulators and Reactors.
14. (March 1925) Standards for Instrument Transformers.
15. (Dec. 1924) Standards for Industrial Control Apparatus.
16. (July 1925) Standards for Railway Control and Mine Locomotive Control Apparatus.
19. (July 1925) Standards for Oil Circuit Breakers.
22. (July 1925) Standards for Disconnecting and Horn-Gap Switches.
30. (August 1925) Standards for Wires and Cables.
34. (June 1922) Standards for Telegraphy and Telephony.
36. (June 1922) Standards for Storage Batteries.
37. (July 1925) Standards for Illumination.
38. (March 1925) Standards for Electric Arc Welding Apparatus.
39. (July 1925) Standards for Electric Resistance Welding Apparatus.
41. (July 1925) Standards for Insulators.
42. (March 1924) Standard Symbols for Electrical Equipment of Buildings.

Sections in Preparation.

No. 2. Standard Definitions and Symbols.
4. Standards for the Measurement of Test Voltages in Dielectric Tests.
9. Standards for Induction Motors and Induction Machines in General.
12. Standards for Prime Mover and Generator Units.
20. Standards for Air-Circuit Breakers.
21. Standards for Lever Switches and Enclosed Lever Switches.
27. Standards for Switchboards.
28. Standards for Lightning Arresters.
29. Standards for Electric Railways.
33. Standards for Electrical Measuring Instruments.
35. Standards for Radio Communication.

(SEC. 1)—GENERAL PRINCIPLES

The importance from a practical standpoint of the "General Principles upon Which the A. I. E. E. Standards Are Based" which appeared as Chapter 1 of the 1922 Edition has been very considerably reduced. The impossibility of rigidly applying the principle to many practical cases has been mentioned before. This basic material is of very considerable value to those interested in the formulation of standards but it has led to confusion when the attempt has been made to use it in working standards. In the new edition this material is included as Section 1 but it does not have the force or standing of rules for rating or testing. To quote the preface of this new section: "The limits of temperature and temperature rise given in this pamphlet are not limits for the rating or testing of electrical machinery. The pamphlet deals with the general considerations upon which rating limits are based."

The only temperature limits given in the revised Standards (with the exception of certain operating temperature limits given for traction motors) are the limiting temperature *rises* corresponding to the standard test rating. Total hottest spot temperatures for the different classes of insulation, conventional allowances, and the corresponding total observable temperatures have been completely eliminated from the sections dealing with machinery or apparatus standards.

In the A. I. E. E. Standards from the 1914 to the 1922 Editions inclusive, the Institute recognized three methods of temperature measurement and only in a few instances was one method definitely specified in a particular application. In the 1922 Edition, for example, Section 1001 states:

"The General Principles stated in Section 1000 permit the use of whichever method (of temperature measurement) is best suited to the class of machine, or part thereof to be tested, by introducing appropriate values for the limiting observable temperature by each method."

Table 200, Section 2230 indicated in many important instances temperature limits for both thermometer and resistance measurements and therefore, according to A. I. E. E. standards, either method could be required in an acceptance test unless the purchaser and manufacturer had agreed on a more definite program in some other way.

In distinction to this indefinite program regarding the application of the several recognized methods of temperature measurement in previous editions, the 1925 standards definitely specify the method (or, in some instances, the two methods) that shall be used in each case.

Some of the more important additions and changes made in the various sections are given in the concluding part of this article. To give all of the important change would be impossible within reasonable space limits and the reader is referred to the standards themselves for more complete information.

(Sec. 5)—Standards for Direct-Current Generators and Motors

(1) Limiting Temperature Rises. No changes have been made in temperature rises as specified in previous editions. The temperature rise for insulated windings is 50 deg. measured by thermometer. The unsettled situation existing in connection with the standard rating of general purpose motors is recognized by the following note appearing with the table of limiting temperature rises:

"The temperature limits on which the rating of general purpose motors is based are under discussion at the present time and no agreement has yet been reached. In order that work being done in this connection may not be influenced or impeded, the Institute refrains from taking any action at the present time towards revising its rules for this class of machinery."

(Sec. 2)—Shutting-Down Machine at End of Temperature Test. In d-c. machines it is very difficult to correct temperatures taken on the rotating part after shut-down for the decrease in temperature that occurs during shut-down. In order to more completely standardize the conditions of test a new rule has been added requiring machines to be shut-down within definite times. Up to and including 50 kw. this is one minute; up to and including 200 kw. it is two minutes and for still larger machines three minutes.

(Sec. 3)—Successful Commutation Defined. A new definition is included that recognizes normal maintenance as the criterion of successful commutation.

(Sec. 4)—Brush Friction. Conventional values of 8 watts per sq. in. of brush contact surface per 1000 ft. per min. peripheral speed for carbon and graphite brushes and 5 watts for metal graphite brushes are established for calculation of brush friction. If these values are not acceptable to either party the brush friction is to be measured as heretofore.

(Sec. 5.) Stray Load Losses. A very important change has been made by including stray load losses in the total losses from which the conventional efficiency is determined. These are calculated as one per cent of the output for all loads; *i. e.*, 1 per cent of the rating at full load and 0.05 per cent of the rating at half load. This new rule does not apply to motors of 200 h. p. at 575 rev. per min. and smaller. This new rule will operate to reduce the full load efficiency, which is as usually specified, one per cent.

(Sec. 7)—Standards for Alternators and Synchronous Motors

(1) Limiting Temperature Rises. Two tables of limiting temperature rises are given, one for steam-turbine driven alternators and a second for other synchronous machines. For both classes of machines, rises by embedded detectors (between coil sides) are 60 deg. for Class A insulation and 80 deg. for Class B insulation. The option of using higher temperature rises for Class B insulation (if such higher figures are the subject of special guarantee by the manufacturer) permitted by the 1914 to 1922 editions (inclusive) has been eliminated in this edition. For steam-turbine generators the limiting temperature rise of the rotor winding is 90 deg. by resistance for Class B insulation; and for lower speed synchronous machines the corresponding figures for field windings are 60 deg. and 80 deg. for Class A and B insulation, respectively. An important change has been made in the method of temperature measurement; all insulated field winding temperatures are now to be measured by resistance.

The detector method of measurement has been specified for turbine generators above 750 kv-a. in rating and for other machines above 1500 kv-a. These limits replace the 20-in. core length used in previous editions.

These limiting temperature rises and methods of measurement were adopted as international standards at the recent Hague meeting of the I. E. C., with the exception that the detector method was specified for use only on much larger machines.

This national and international agreement on Class B insulation temperature rises is a very important step forward and is a matter of congratulation among engineers interested in this class of machinery.

(2) Zero Power-Factor Method of Loading for Temperature Tests. This method of loading has been rapidly growing in favor during the past ten years and is now recognized as an approved method in this edition of the standards.

(3) Short Circuit Requirements. It is definitely specified that all synchronous machines shall be capable of withstanding short circuit when tested under conditions of no-load rated frequency and 110 per cent rated voltage. The higher voltage is intended to

compensate for the difference between no load and rated load flux.

(*4*) *Variations in Armature Current* present in synchronous motors driving air compressors or other machinery with reciprocating parts is limited to 66 per cent of rated current. This value was first adopted by the Electric Power Club and the American Society of Refrigerating Engineers and was accepted by the A. I. E. E. Committee.

(Sec. 8)—Standards for Synchronous Converters

(*1*) *Limiting Temperature Rises.* The temperature rises are unchanged, except that the 65 deg. rise previously specified for commutators of all commutating machines has been reduced to 60 deg.

(*2*) *Shutting-Down Converter at End of Temperature Test.* A rule similar to the one previously discussed in connection with d-c. machines is added. A single limit of three minutes for all converters is specified. A single limit is permissible on account of the relatively large size of the converters.

(*3*). *Successful Commutation Defined.* The same new definition is given for converters as for d-c. machines.

(*4*) *Power Factor Limitations.* A new requirement is added to the effect that all converters rated at unity power factor shall be capable of operating without dangerous heating at 98 per cent power factor. This is intended to provide only against unintentional departures from unity power factor.

(*5*) *Brush Friction.* The same conventional method of determining brush friction, as provided in the d-c. machine section, is included in the converter section.

(*6*) *Stray Load Losses.* Stray load losses are included in the conventional efficiency as one per cent of the output. In previous editions, the stray load losses were omitted. This change will have the result of reducing efficiencies, as previously calculated, 1 per cent at full load.

(Sec. 10)—Standards for Fractional Horse Power Motors

In previous editions of the Standards fractional h. p. motors have not been distinguished from larger motors of the same types. The standards included in this section are essentially the same as for larger motors, except where the difference in size has led to different practise, as, for example, in the case of small motors, the input-output method of efficiency determination is the preferred method. The present situation, regarding the rating of general purpose motors, is recognized by the insertion of the same note, as quoted in the comments on the Direct-Current Machinery Section.

(Sec. 11)—Standards for Railway Motors

This section is of more than usual interest, because the Working Committee responsible for it has included in it some operating recommendations, but this has been done in a way that clearly distinguishes them from the rules concerning the standard test rating.

In a section headed "Service Conditions," there is a table of "limiting observable temperatures recommended for service." These temperatures are given as a guide to operating engineers in the every-day application and use of railway motors. These are total temperatures and include the cooling-air temperature. "Peak Values" corresponding to 40 deg. air temperature and "normal values" corresponding to 25 deg. air temperature are both given. This table is quoted below, so that it may be compared with the temperature rises given later for the test rating:

LIMITING OBSERVABLE TEMPERATURES RECOMMENDED FOR SERVICE

Method of Temperature Determination	Peak Values		Normal Values	
	Resistance	Thermometer	Resistance	Thermometer
	deg. cent.		deg cent.	
Class A Insulation......	125	105	110	90
Class B Insulation......	145	120	130	105

In another part of the Railway Motor Standards are sections on Rating and Heating, referring to the test rating. *Temperature rises* are given for various parts of the motor for a one-hour rating and for continuous rating and for Class A and Class B insulations and for ventilated and totally enclosed motors. For the purpose of illustration the following temperature rises for armature and field windings are quoted:

	Type Enclosure	Method Temp. Meas.	Limiting Temperature Rise			
			One Hour Rating		Continuous Rating	
			Class A	Class B	Class A	Class B
Arm. and Fld. Windings......	Ventilated	Resist	100	120	85	105
		Thermo	80	95	65	80
	Totally Enclosed	Resist	110	130	95	115
		Thermo	90	105	75	90

It will be noted that the temperature rises given for the continuous test rating on stand test are equivalent to the limiting observable temperatures recommended for service with average air temperature of 25 deg. cent.

An important change has been made in the standard test conditions regarding ventilation. In the 1922 and previous editions the test conditions included "with the motor covers arranged to secure maximum ventilation without external blower." This resulted in tests being made with "covers off." The revised standards provide that "Motors shall be tested with the covers and cooling system, if any, arranged as in service." This is a change in the direction of agreement between test conditions and "usual service conditions."

These American railway motor temperature rises for test rating were adopted at the recent Hague meeting of the International Electrotechnical Commission.

(Sec. 13)—Standards for Transformers, Induction Regulators and Reactors

(*1*) *Altitude Correction.* For air-cooled oil-immersed apparatus the correction for temperature rises observed at high altitudes is 0.4 per cent for each 100 meters above 1000 meters instead of 1 per cent as in the previous editions. This change is based on recent experimental work.

(*2*) *Short Circuit Current of Transformers.* A new requirement is included that transformers shall be capable of withstanding, without injury, for two seconds a short circuit across the secondary terminals under specified service conditions. Exceptions are made in the case of auto-transformers, certain low reactance transformers, and transformers which are to be directly connected to other apparatus possessing inherent reactance.

(*3*) *Dielectric Test Voltages.* Important new material appears in the revised Standards concerning transformers with graded insulation and transformers tested by induced voltage. Transformers having windings with graded insulation and directly and permanently grounded shall be tested by induced voltage with connections so made that the ungrounded or line terminals shall receive test voltage to ground not less than 2.73 times the normal voltage developed by the winding plus 1000 volts. If this test does not also produce between terminals two times the rated voltage of the circuit plus 1000 volts, an additional test to produce this result shall be made.

When transformers are tested by inducing the required voltage in the winding, frequencies higher than normal are generally employed in order to avoid oversaturation in the core, and also, in the case of large transformers, to enable the test to be made with testing equipment of reasonable size. Recent experimental work by Montsinger at Pittsfield and Vogel at Pittsburgh has shown that the severity of the dielectric test increases with frequency in such rates that, for equal severity, the time should be reduced in the same ratio as the frequency is increased. For purposes of standardization the following times are used for the respective frequencies:

Frequency	Time in Seconds
120 and below	60
180	40
240	30
360	20
400	10

Considerable new material relating to induction regulators has been added to the Standards. Limiting temperature rises, method of loading for temperature tests, short-circuit current, efficiency and losses are included for the first time.

(Sec. 9)—Standards for Induction Motors
(*in preparation*)

This section is largely a collection of previously existing A. I. E. E. Standards, relating to induction machines. The definitions have been revised and new definitions have been added for the *squirrel-cage induction motor, wound rotor induction motor, induction frequency converter* and "*slip*".

Shutting-Down Machines at End of Temperature Run. When the stopping time is limited to specified values, no correction of observed temperatures is required. These values are the same as for d-c. machines:

Up to and including 50 h. p.	1 minute
Above 50 h. p. and including 200 h. p.	2 minutes
Above 200 h. p.	3 minutes

Stray Load Losses. The 1922 Standards specified a method for measuring stray load losses in induction machines, but also stated:

> "In windings consisting of relatively small conductors, these eddy-current losses are usually negligible."

The specified method of measuring these losses—with rotor removed—has seldom been used in practise, and stray load losses have usually been neglected. In the 1925 revision, the following provisions have been incorporated:

> "Stray Load Losses. In induction machines, no allowance for stray load losses shall be included."

A footnote calls attention to the fact that stray-load losses may be considerable, if the primary winding contains conductors more than ⅜ in. in depth in a 60-cycle machine. Modern designs use conductors considerably smaller than this.

Rating of Elevator Motors. A new paragraph has been added which is the same as the previously existing Electric Power Club Standard.

Standards for Industrial Control Apparatus

In the 1922 Standards, Industrial Control Standards were grouped with switching, circuit breakers, and protective apparatus. No distinction was drawn between the different apparatus and general conditions existing in the industrial field and in the field of power supply. The separation of these diverse kinds of equipment into a number of separate sections has led to a considerable increase in material and a general improvement in these standards.

The new material in Industrial Control Standards mainly concerns limiting temperature rises, conditions and methods of making temperature tests and limitations other than heating, such as range of operating voltage for contactors, test for operation at minimum voltage, durability test and tests to determine successful operation.

This section has the distinction of being the first section to be given the status of an American Standard under the procedure of the American Engineering Standards Committee. This American Standard was sponsored jointly by the Electric Power Club and the A. I. E. E.

Standards for Oil Circuit Breakers

Considerable new material relating to rating of oil circuit breakers has been included. This material, while new to the A. I. E. E. Standards, is well established in the practise of the industry.

Standards for Insulators

This is an entirely new specification, and is the result of painstaking work on the part of a representative group of engineers during the past three years. It is essentially a test specification and prescribes procedure, in considerable detail, for both pin- and suspension-type insulators.

Standards for Electrical Measuring Instruments (*in preparation*)

This is another wholly new standard and is a good example of the cooperation that exists between the technical committees of the Institute and the Standards Committee. This section first appeared as an Institute paper by H. B. Brooks, prepared under the direction of the Technical Committee on Instruments and Measurements. A Working Committee of the Standards Committee is now putting the section in suitable form for approval—using the Brooks paper as a basis.

These are the more important changes and additions to be found in the new edition of the Institute Standards. It is confidently believed that this edition will prove a worthy successor to the long line of older editions, and that it will serve the industry in even greater measure.

ONE GENUINE METHOD OF SOLVING THE AUTOMOBILE HEADLIGHT PROBLEM

Possession of a little card, signifying that the bearer thereof has expended seventy-five cents to have his automobile headlights tested and adjusted, has not solved the problem of automobile headlight glare. On paper the theory sounds very well, but in practise there are a number of conditions which shake its security. Every road bump, every car track, every vibration constitutes one of these mitigating conditions.

It is not enough to conform to the letter of the law once or twice a month by visiting headlight-testing stations. It helps the motorist who has to look into glaring headlights not one whit, if after leaving the testing stand, a jar or a twist will leave the lights of any given car in position to blind everyone into whose range they come. No amount of legislation nor even of testing and adjusting can prevent glare from strong headlights along rolling road-beds.

Like many another panacea, the remedy has been applied to the effect rather than the cause; the fact remains that roads are not ideal in contour, and even perfect adjustment does not prevent a car coming up over a rise in the road from sending its perfectly focused rays full into the eyes of drivers approaching on the other side.

Yet there is a way to remedy the condition that is not dependent on law enforcement. It consists of illuminating the highways scientifically.

Regardless of road conditions, regardless of the condition of the apparatus of the individual cars that traverse them, scientific highway lighting will be uniform.

The idea carries with it commercial possibilities to the electrical industry, naturally, but more than that it will bring satisfaction that the problem is being solved in the best and most sensible way. The success of street lighting, where illumination has been the chief object sought rather than mere ornament, has brought forth as a by-product this vision of highway illumination potentialities. That the headlights of an automobile are practically unnecessary on well-lighted streets has suggested that highways might be made safe in the same manner.

The electrical industry is not the only one which will profit from highway illumination. Tests made recently on a stretch of highway in the East have demonstrated actually by count that without altering the highway traffic could be increased 100 per cent by having them well lighted. Practically all the trucking load upon highways is carried at night. With well-lighted highways the amount of trucking over highways can be increased 100 per cent, the experiment proved, and the highways still remain safe for traveling motorists.—*Journal of Electricity*, November 1, 1925.

KILOCYCLE-METER CONVERSION TABLE

There is increasing tendency in radio practise to use radiofrequencies in kilocycles rather than wave lengths in meters. "Kilo" means a thousand, and "cycle" means one complete alternation. The number of kilocycles (abbreviated kc.) indicates the number of thousands of times that the rapidly alternating current in the antenna, transmitting set, or receiving set repeats its flow in either direction in one second.

The bureau has just issued in chart form a "Kilocycle-Meter Conversion Table." It is Miscellaneous Publication No. 67 and replaces Letter Circular No. 123 of January 27, 1925. The table is printed on a single sheet of cardboard and can be posted in a convenient place for ready reference. (Copies may be obtained for 5 cents each from the Superintendent of Documents, Government Printing Office, Washington, D. C.)

The table gives accurate values of kilocycles corresponding to any number of meters and vice versa. The table gives values for every 10 kilocycles or meters, and is entirely reversible; that is, for example, 50 kilocycles is 5996 meters and also 50 meters is 5996 kilocycles. The range of the table is from 10 to 10,000 kc. (10,000 to 10 m) and this can be extended in either direction by changing the decimal point.

Transmission Systems with Over-Compounded Voltages

BY H. B. DWIGHT[1]

Member, A. I. E. E.

Synopsis.—A usual method of calculating a transmission line with transformers, in which the voltage is held constant at both ends by synchronous condensers, is to use the circle diagram method. It is often advisable to use "over-compounded" voltage instead of constant voltage; that is, to increase the voltage as the load increases. Methods of calculation are given in this paper for two cases, first with over-compounded generator voltage and constant receiver voltage, in which case the diagram is a circle, and second, with over-compounded voltage at both generator and receiver, in which case the diagram is an ellipse. Examples are given and the diagrams are shown in Fig. 2.

A short discussion is given of the advantages and limitations of using over-compounded voltage.

* * * * *

IT is a very usual practise to control the station voltages of transmission systems by automatic voltage regulators, which adjust the field currents of generators and synchronous condensers so that the desired voltages are obtained. In such cases, very great advantages are obtained in many stations by maintaining a higher voltage at a time of heavy load than at a time of light load. This may be called "over-compounded voltage," and can be easily accomplished by means of a simple arrangement with an automatic voltage regulator, which is often called line drop compensation. One of the most common methods of producing line-drop compensation is to put a few turns of winding, carrying current from series transformers, on the magnet of the relay which controls the voltage. These series ampere-turns usually amount to not more than about 25 per cent of the ampere-turns of the shunt winding, which is the main winding. Therefore, the result is that, at no load, the main winding operates the regulator so as to produce a certain voltage. With load conditions and the series winding opposing the shunt, a higher voltage is necessary before the regulator will operate; therefore, a higher voltage than at no load is maintained.

A somewhat similar arrangement to give over-compounded voltage is frequently provided with induction voltage regulators.

Advantages of Over-Compounded High-Tension Voltage

The statement is sometimes made that the voltage supplied to a certain customer or city by a transmission system should have not more than a specified amount of variation, say five per cent. Where such a statement is made, it practically always refers to "under-compounded" voltage; that is, the voltage variation is caused by the load and the voltage is low at times of heavy load. It is evident that, if a voltage of 12,000 volts or higher is under-compounded, then circuits of 2300 or 115 volts will be still more under-compounded due to the drop in the intervening transformers and lines at full load. If the higher voltage is over-compounded, then the drop in transformers and lines tends to decrease the variation in the distribution voltage instead of increase it.

It can be stated that, in general, twice as much over-compounding as under-compounding of a circuit of 12,000 volts or higher can be allowed for the same amount of inconvenience and for the same necessity of using feeder voltage regulators. In reality, the circuits which feel the disadvantage of voltage variation most are 115-volt circuits, where changes in voltage are noticeable at once in the changed brightness of lamps. Voltage variation in 2300-volt circuits is often inconvenient mainly because it causes variation in the connected 115-volt circuits. Slightly over-compounded voltage on a motor circuit is not very disadvantageous, for low voltage is most liable to occur out of working hours, when there is light load on the power system. Such an arrangement is the least troublesome, and further, is economical, for the core loss of transformers and motors is reduced during the night when they are giving what is often practically only stand-by service. Good speed and good starting torque and pull-out torque in induction motors are especially desirable when loads are heavy, and these are all helped by over-compounded voltage.

It may be said that over-compounded voltage on circuits operating at greater than 115 volts is more desirable than constant voltage or under-compounded voltage, in almost every case. This is true for practically any customer, city, or place where there are generators, synchronous condensers or induction regulators to give control of the voltage; but it is particularly true of the generating end of long transmission lines. Where there is an appreciable amount of charging current, at no load the equivalent voltage at the generator terminals must be lower than at the load end with no synchronous condensers connected, due to the reactance of the transformers and of the line. However, it would not be economical to operate the generators always at this low voltage, since this would involve greater resistance loss and a larger rating of synchronous condensers if such are used for voltage regulation. The generators at full

1. Mass. Inst. of Technology.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., Feb. 8-11, 1926.

load should be operated at full rated voltage. It is also, in many cases, inadvisable to operate the generators at constant full rated voltage, for this produces too high a voltage at the distant end at no load, necessitating delay when starting to put the synchronous condensers on the line for even a small amount of load, or for paralleling with other lines. Unduly high voltage increases strain on the insulation and produces trouble in the generating station in handling the charging current. Accordingly, if automatic voltage regulators are used, as is generally the case with long transmission lines, they should, if possible, be adjusted for a moderate amount of over-compounding of the voltage rather than for constant voltage. It is fortunate that the over-compounding is practically proportionate to the true kilowatt load, and is not appreciably affected by the quadrature charging current.

Where there are several generators in a station often only one or two are used to carry the load in the middle of the night. At such time each generator should have less amount of compounding than it would have when the entire station is operating. However, since the over-compounding or line-drop compensation feature can be reduced or cut out by merely turning a dial on the voltage regulator, it is not difficult to do this at times when the number of generators operating in the station is changed. It is also possible to take the current for the series coils of the regulators from a current transformer carrying the total load of the entire station. This will give the same over-compounding for the station regardless of the number of generators in operation.

Most Advisable Amount of Over-Compounding

The question as to how much over-compounding of the voltage should be used in a transmission system is not so much a question of design as of operation, for the over-compounding will be limited in most cases to a comparatively small percentage by operating considerations.

Transmission lines over 100 miles long cost considerably more than the synchronous condensers used to control their voltage. Consequently, it pays to install synchronous condensers sufficient to maintain the line at nearly rated voltage in all parts when it is fully loaded. If the line current at the load end has a very low leading power factor, its resistance loss and, what is more important, its stability will usually be improved by putting part of the synchronous condensers in an intermediate substation.

The voltages to be maintained with long lines at light load and no load will depend mainly on the method considered desirable for starting up the transmission system; whether the generators are to be thrown on the line alone or on sections of it; whether the synchronous condensers are to be started and adjusted for lagging power factor before connecting on any load; or whether the generators are to be brought up from zero speed, together with the synchronous condensers.

With lines shorter than 100 miles, the cost of synchronous condensers becomes of greater relative importance, because the cost of the lines is proportionately less. The cost of condensers is usually compared with the cost of more or heavier transmission circuits.

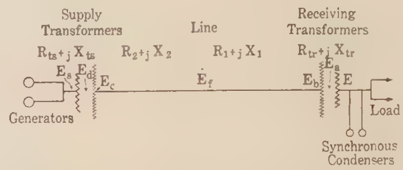

Fig. 1—Scheme of Connections of Transmission System

The question of the amount of voltage variation to be allowed on low voltage circuits depends on the standard set in different localities for different classes of load. This standard is maintained in practical operation by installing more circuits, transformers and induction feeder regulators in the lower voltage parts of the system, as well as by improving conditions in the higher voltage parts.

A certain amount of over-compounding on the higher voltage circuits will generally help to maintain the above standard. How far this can be carried is a matter on which only a small amount of data has been collected or published. An investigation on actual systems as to how much over-compounding can be used under different conditions before real practical disadvantages are encountered would be valuable.

Where there is no load to be supplied close to the generators, over-compounding up to about 25 per cent at the generators can be used. If loads are supplied directly from the generator bus-bars, a smaller amount of over-compounding must be used, the amount depending on whether the power passes once or twice through transformers before it is used by motors or lamps, and on whether the load curve of the local load throughout the day corresponds closely with the load curve of the generator load.

In conclusion, it is generally advisable to use as much over-compounding at any point as experience shows can be used without interfering with the accepted standards of good maintenance of voltage in the different low-voltage circuits of the system. A small percentage of over-compounding can be used on high-tension circuits at load points and a larger percentage, amounting in some cases to as much as 25 per cent, can be used at generating stations.

Calculation of Lines Having Over-Compounded Voltage

A very convenient method of calculating the electrical behavior of a transmission line or system provided with synchronous condensers is to draw the circle

diagram showing the reactive kv-a. required from the synchronous condensers at various loads, the step-up and step-down transformers being taken into account[2]. In the present paper, the method of calculation is extended to cover the case of over-compounded generator voltage and constant receiver voltage, for which case the diagram is a circle. An extension of the calculation is also given to cover the case of over-compounded voltage at both generator and receiver and in this case, the diagram is not circular but elliptical. Examples are given and the resulting diagrams are shown in Fig. 2.

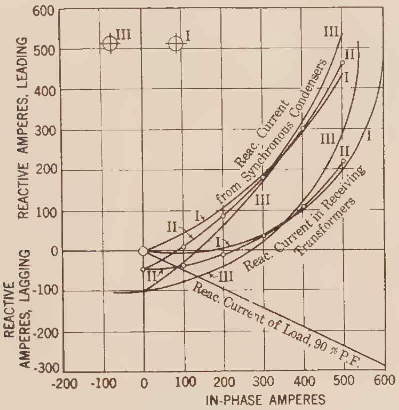

Fig. 2— I. Over-Compounding at Generator End
II. Over-Compounding at Both Ends
III. Constant Voltage at Both Ends

A solution for the case of over-compounded generator voltage and constant receiver voltage has been published using the method of the equivalent π line[3].

Calculation for Line and Transformers, with Over-Compounded Generator Voltage and Constant Receiver Voltage

Numerical values, except for $(P + j\,Q)$ which always appears, are to be found for the following quantities:

Current in secondary of receiving transformers:

$$I_a = P + j\,Q + P_c \text{ amperes per conductor} \qquad (1)$$

Voltage induced in receiving transformers:

$$E_a = E + \frac{1}{2} I_a\,(R_{tr} + j\,X_{tr}) \text{ volts to neutral} \qquad (2)$$

Current in primary of receiving transformers:

$$I_b = I_a + E_a\,(G_{tr} + j\,B_{tr}) \text{ amperes per conductor} \qquad (3)$$

Voltage at receiving end of transmission line:

$$E_b = E_a + \frac{1}{2} I_b\,(R_{tr} + j\,X_{tr}) \text{ volts to neutral} \qquad (4)$$

2. "Electrical Characteristics of Transmission Systems," by H. B. Dwight, Trans. A. I. E. E., Vol. 41, 1922, page 781.

3. "Regulator Settings for Long Lines," by L. F. Woodruff, *Electrical World*, August 30 and September 6, 1924.

Voltage at a point f where the conductor or spacing is changed but not where the voltage is controlled:

$$E_f = E_b\left(1 + \frac{Y_1 Z_1}{2} + \frac{Y_1^2 Z_1^2}{2 \times 3 \times 4} + \ldots\right)$$

$$+ I_b Z_1\left(1 + \frac{Y_1 Z_1}{2 \times 3} + \frac{Y_1^2 Z_1^2}{2 \times 3 \times 4 \times 5} + \ldots\right)$$

$$\text{volts to neutral} \qquad (5)$$

Current at point f:

$$I_f = I_b\left(1 + \frac{Y_1 Z_1}{2} + \frac{Y_1^2 Z_1^2}{2 \times 3 \times 4} + \ldots\right)$$

$$+ E_b Y_1\left(1 + \frac{Y_1 Z_1}{2 \times 3} + \frac{Y_1^2 Z_1^2}{2 \times 3 \times 4 \times 5} + \ldots\right)$$

$$\text{amperes per conductor} \qquad (6)$$

Y_1 and Z_1 are the admittance and the impedance of the line from b to f.

Voltage at supply end of transmission line:

$$E_c = E_f\left(1 + \frac{Y_2 Z_2}{2} + \frac{Y_2^2 Z_2^2}{2 \times 3 \times 4} + \ldots\right)$$

$$+ I_f Z_2\left(1 + \frac{Y_2 Z_2}{2 \times 3} + \frac{Y_2^2 Z_2^2}{2 \times 3 \times 4 \times 5} + \ldots\right)$$

$$\text{volts to neutral} \qquad (7)$$

Current at supply end of transmission line:

$$I_c = I_f\left(1 + \frac{Y_2 Z_2}{2} + \frac{Y_2^2 Z_2^2}{2 \times 3 \times 4} + \ldots\right)$$

$$+ E_f Y_2\left(1 + \frac{Y_2 Z_2}{2 \times 3} + \frac{Y_2^2 Z_2^2}{2 \times 3 \times 4 \times 5} + \ldots\right)$$

$$\text{amperes per conductor} \qquad (8)$$

Y_2 and Z_2 are the admittance and the impedance of the line from f to c.

Voltage induced in supply transformers:

$$E_d = E_c + \frac{1}{2} I_c\,(R_{ts} + j\,X_{ts}) \text{ volts to neutral} \qquad (9)$$

Current in primary of supply transformers:

$$I_d = I_c + E_d\,(G_{ts} + j\,B_{ts}), \text{ amperes per conductor.}$$
$$= C + j\,D = \text{current at generator terminals.} \qquad (10)$$

Voltage at generator terminals:

$$E_s = E_d + \frac{1}{2} I_d\,(R_{ts} + j\,X_{ts}) \text{ volts to neutral}$$
$$= A + j\,B$$
$$= E_{os} + L_s\,I_d \qquad (11)$$

Equation for circle diagram:

$$E_{os} = E_s - L_s\,I_d \text{ volts to neutral}$$
$$= E' + j\,E'' + (P + j\,Q)\,(R' + j\,X') \qquad (12)$$

Quantities required for above equations (referring to a three-phase system):

$P + j\,Q$ = Load current + reactive current from synchronous condensers. This is always

expressed by letters in the above calculation.

P_c = Current for average loss in synchronous condensers.

E = Equivalent high-tension voltage at low-tension side of receiving transformers, in volts to neutral.

R_{tr} = Equivalent high-tension resistance from line to neutral of receiver transformers.

If the resistance is given in per cent,

$$R_{tr} = \frac{\text{Per cent resistance} \times E^2}{100{,}000 \times \text{kv-a. per phase}} \tag{13}$$

X_{tr} = Equivalent high-tension reactance from line to neutral of receiver transformers. If the reactance is given in per cent,

$$X_{tr} = \frac{\text{Per cent reactance} \times E^2}{100{,}000 \times \text{kv-a. per phase}} \tag{14}$$

It is assumed in equations (**2**) and (**4**) that, so far as the magnetizing current is concerned, the transformer impedance is equally divided between the primary and secondary. If the division is more accurately known, the actual values of primary and secondary impedance can be used.

$G_{tr} + j\,B_{tr}$ = Admittance (equivalent high-tension) for core loss and magnetizing current of receiver transformers at average voltage. If these characteristics are given in per cent,

$$G_{tr} = \frac{\text{Per cent core loss}}{100} \times \frac{1000 \times \text{kv-a. per phase}}{E^2} \tag{15}$$

and

$$B_{tr} = -\frac{\text{Per cent magnetizing current}}{100} \times \frac{1000 \times \text{kv-a. per phase}}{E^2} \tag{16}$$

B_{tr} is a negative quantity.

The characteristics of the supply transformers are denoted by the letters $t\,s$ as in R_{ts}, etc.

The point f denotes a place in the transmission line where the line characteristics change due to different conductor or spacing. A constant load may be assumed for this point without changing the form of the calculation. However, it is not to be assumed that the voltage is controlled at this point, for if it were, a circle diagram would have to be calculated as far as f, and another diagram for the remainder of the transmission system. Other points g, h, etc., similar to f, can readily be included in the calculation.

$Y_1 = G_1 + j\,B_1$, the admittance of the line from b to f.

$Z_1 = R_1 + j\,X_1$, the impedance of the line from b to f.

The subscript (**2**) denotes the characteristics of the line from f to c, as in Y_2, etc.

The series in $Y\,Z$ are very convergent at commercial frequencies and can be quickly calculated. It may be noted that

$$1 + \frac{Y_1 Z_1}{2} + \frac{Y_1^2 Z_1^2}{2 \times 3 \times 4} + \ldots = \cosh \sqrt{Y_1 Z_1}$$

and

$$1 + \frac{Y_1 Z_1}{2 \times 3} + \frac{Y_1^2 Z_1^2}{2 \times 3 \times 4 \times 5} + \ldots = \frac{\sinh \sqrt{Y_1 Z_1}}{\sqrt{Y_1 Z_1}}$$

E_{os} is a quantity whose absolute value is equal to that of the equivalent high-tension voltage at the generator terminals at no load. Only the absolute value of E_{os} is made use of in the calculation in this paper. The phase of the quantity E_{os} changes as the load changes, and so E_{os} cannot be considered as a constant nor as a complete representation of the no-load voltage. The reason for this is that the automatic regulator maintains the absolute value of the voltage according to the last part of (**11**), but it has no power to alter the phase of the voltage.

L_s is a measure of the over-compounding of the voltage, or the line drop compensation. It is equal to the rise in equivalent high-tension voltage produced by one ampere of current (equivalent high tension) in phase with E_s.

Circle Diagram. Since equation (**12**) is of the same form as the equation for a constant-voltage transmission line, a circle diagram may be drawn for the transmission system with over-compounded voltage at the generator end. Since E, the load voltage, is constant, the values of current may be multiplied by

$$\frac{3\,E}{1000}$$

to give kw. and reactive kv-a. as in Reference 1. However, where the voltage is varying, it is desirable to keep account of the current and voltage rather than the kv-a., and so the circle diagram equations are given here in terms of amperes.

The center of the circle is the point (a', b') where

$$a' = -\frac{E'\,R' + E''\,X'}{R'^2 + X'^2} \text{ amperes} \tag{17}$$

$$b' = +\frac{E'\,X' - E''\,R'}{R'^2 + X'^2} \text{ amperes} \tag{18}$$

The radius is

$$c' = +\frac{E_{os}}{\sqrt{R'^2 + X'^2}} \text{ amperes} \tag{19}$$

The circle shows the reactive current at the receiver end of the line plotted on values of in-phase current at the receiver end.

In order to plot the reactive current required from the synchronous condensers, first draw a straight line at angle θ below the base line, where $\cos\theta$ is the power factor, lagging, of the load. If the power factor is not the same at all loads, the line will not be straight, but will be a curve showing the reactive current of the load from no load to full load. By means of a pair of dividers add the reactive current of the load to the corresponding ordinate of the circle, thus plotting the curve of current required from the synchronous condensers. This curve is an ellipse when $\cos\theta$ is constant. (See Fig. 2).

Circle Diagram Limit of Load.

$$\text{Maximum Load} = c' + a' \text{ in-phase amperes} \qquad (20)$$

This is numerically less than c' when a' is a negative quantity, and greater than c' when a' is positive. It may be read from the circle diagram, as it is the farthest distance to the right reached by the circle. It is a useful point to locate on the diagram before drawing the circle, as is also the bottom point of the circle, $(a', b' - c')$. It assists in drawing the circle to have these two points through which the circle is to pass.

The "stability limit" of load is usually somewhat less than the circle diagram limit, and of course, in the operation of a transmission line, neither limit must be reached.

Calculated Value of Reactive Current.

A direct calculation of the reactive current is more precise than a reading from the circle diagram, and is less work than a trial and error method. The value of the reactive current in the circuit, Q, for a given in-phase current P, may be found from the following equation:

$$(b' - Q)^2 = c'^2 - (P - a')^2 \qquad (21)$$

First, find the value of the right hand side of the equation. Then take the square root and subtract b'. The reactive current required from the synchronous condensers is equal to

$$Q + P\frac{\sin\theta}{\cos\theta} \text{ amperes} \qquad (22)$$

where the in-phase current is P amperes and the lagging power factor is $\cos\theta$. It should be remembered that b' is a positive quantity and a' may be positive or negative. It is worth while checking the results of equations (**21**) and (**22**) by drawing the circle diagram and obtaining the same results graphically.

Concentric Circles. Since a' and b' which give the center, are independent of E_{os} and since the radius c' is directly proportional to E_{os}, a number of circles corresponding to different values of E_{os} may be drawn about the same center.

Total Losses. The losses in the transmission system for a given power load are

$$\frac{3}{1000}(A\,C + B\,D - E\,P) \text{ kw.} \qquad (23)$$

P is determined by the power load. Then Q must be found from the circle diagram or equation (**21**). Then A, B, C and D can be found from equations (**10**) and (**11**), for which numerical coefficients have already been obtained.

Efficiency of the transmission system

$$\text{Efficiency} = \frac{100\,E\,P}{A\,C + B\,D} \text{ per cent} \qquad (24)$$

Kw. at supply end of system

$$\frac{3}{1000}(A\,C + B\,D) \text{ kw.} \qquad (25)$$

Kv-a. at supply end

$$\frac{3\,E_s\sqrt{C^2 + D^2}}{1000} \text{ kv-a.} \qquad (26)$$

Power factor at supply end

$$\frac{100\,(A\,C + B\,D)}{E_s\sqrt{C^2 + D^2}} \text{ per cent} \qquad (27)$$

Reactive kv-a. at supply end

$$\frac{3}{1000}(A\,D - B\,C) \text{ kv-a.} \qquad (28)$$

When this quantity is positive the reactive kv-a. and the power factor are leading, and when it is negative they are lagging.

Over-Compounded Voltage at Both Supply and Receiver Ends of System

The receiver voltage can be over-compounded when there are synchronous condensers, by using exactly the same kind of apparatus as that used to provide over-compounded voltage at the supply end. The diagram in this case is not a circle, but an ellipse, and so values of Q for different values of P are found by calculation.

If L_r is the rise in equivalent high-tension voltage at the receiver end produced by one ampere of current (equivalent high-tension) in phase with E, then

$$E_o = E - L_r\,P - j\,L_r\,Q$$

as in eq. (**12**). The phase of E_o in the above expression changes as the load changes. Its absolute value is equal to that of the equivalent high-tension voltage at the receiver end at no load. P is in phase with E.

The absolute value of E_o is equal to

$$E - L_r\,P + \frac{(L_r\,Q)^2}{2\,(E - L_r\,P)} \qquad (29)$$

$L_r\,P$ is usually less than 25 per cent of E for any load that the line is to carry. If $L_r\,Q$ is 20 per cent of rated voltage, the third term of (**29**) is less than three per cent of E. It is therefore seen that the quadrature current Q has very little effect on the voltage, and the over-compounding of the voltage or the line-drop compensation is practically proportional to the in-phase current or the true kilowatt load.

In the calculations in this paper the third term of (29) is neglected, and we write

$$E = E_o + L_r P \tag{30}$$

Now evaluate expressions (1) to (12). The quantity $(P + j\,Q)$ will not be a factor as it was in the previous case, but P and Q will now have different numerical coefficients. The final expression as given by (12) is

$$E_{os} = E_s - L_s I_d$$

If a numerical value is assigned to P, this becomes an equation in complex quantities involving Q. E_{os}^2 is equal to the square of the real part of the right hand side plus the square of the imaginary part. This is equivalent to multiplying each side of the equation by its conjugate, that is, by a complex quantity equal to itself except that the sign of the imaginary part is changed. The result is an ordinary quadratic equation in Q, of the form

$$a\,Q^2 + b\,Q + c = 0.$$

Q is given by

$$Q = \frac{-b - \sqrt{b^2 - 4\,a\,c}}{2\,a}$$

The minus sign of the radical is to be used so as to give the normal working part of the curve, corresponding to the lower part of the circle diagram for constant receiver voltage.

Example I

Draw the circle diagram for the following line and transformers, with constant receiver equivalent high-tension voltage 200,000 volts between conductors, no-load equivalent high-tension voltage 183,000 volts between conductors at generators, and 220,000 volts at generators with in-phase current of 355 amperes.

Length of line = 200 miles.
Frequency = 60 cycles.
$R + j\,X = 23.2 + j\,160$ ohms.
$Y = + j\,0.00106$ mho

$$1 + \frac{YZ}{2^2} + \ldots = 0.91637 + j\,0.01195$$

$$1 + \frac{YZ}{2.3} + \ldots = 0.97197 + j\,0.00403$$

$P_c = 8.66$ amperes
$R_{tr} + j\,X_{tr} = 1.33 + j\,24.0$ ohms.
$G_{tr} + j\,B_{tr} = 0.000{,}022{,}5 - j\,0.000{,}187{,}5$ mho
$R_{ts} + j\,X_{ts} = 1.61 + j\,29.0$ ohms.
$G_{ts} + j\,B_{ts} = 0.000{,}018{,}6 - j\,0.000{,}155{,}0$ mho.

The calculation is the same as for Example I, Reference 2, as far as the equation,

$$E_s = 107{,}050 + j\,3340 + (P + j\,Q)\,(23.9 + j\,204.4)$$

Then, the absolute value of $E_{os} = 105{,}850$ volts to neutral.

$$L_s = \frac{127020 - 105850}{355} = 59.8$$

$$E_{os} = 106{,}310 - j\,1610 + (P + j\,Q)\,(-31.3 + j\,203.6)$$
$$= E' + j\,E'' + (P + j\,Q)\,(R' + j\,X')$$

The center of the circle is the point (a', b') where

$$a' = +86.2 \text{ amperes}$$

and

$$b' = +509.2 \text{ amperes}$$

The radius of the circle is

$$c' = +513.8 \text{ amperes.}$$

See Curve I, Figure 2.

Example II

Draw the diagram for the same line and transformers as in Example I, with the same over-compounding of the voltage at the generator end, and with over-compounding at the load end from 182,000 volts at no load to 200,000 volts at 346 in-phase amperes.

$$L_r = \frac{115{,}470 - 105{,}000}{346} = 30.2$$

$E = 105{,}000 + 30.2\,P$
$I_a = P + j\,Q + 8.7$
$E_a = 105{,}000 + j\,100 + P\,(30.9 + j\,12.0) + j\,Q\,(0.674 + j\,12.0)$
$I_b = P\,(1.003 - j\,0.006) + j\,Q\,(1.002 + j\,0.0002) + 11.1 - j\,19.7$
$E_b = 105{,}240 + j\,220 + P\,(31.6 + j\,24.0) + j\,Q\,(1.3 + j\,24.0)$
$E_c = 99{,}740 + j\,2760 + P\,(51.5 + j\,178.4) + j\,Q\,(22.8 + j\,178.0)$
$I_c = P\,(0.894 + j\,0.039) + j\,Q\,(0.894 + j\,0.013) + 9.7 + j\,90.5$
$E_d = 98440 + j\,2970 + P\,(51.6 + j\,191.4) + j\,Q\,(23.3 + j\,191.0)$
$I_d = P\,(0.925 + j\,0.035) + j\,Q\,(0.924 + j\,0.013) + 12.04 + j\,75.2$
$E_s = 97360 + j\,3200 + P\,(51.8 + j\,204.8) + j\,Q\,(23.8 + j\,204.4)$
$E_{os} = 96640 - 3.4\,P - 203.6\,Q - j(1300 - 202.7\,P + 31.4\,Q)$

In calculating the point on the curve for $P = 300$,
$E_{os} = 95620 - 203.60\,Q + j\,(59510 - 31.4\,Q)$

Absolute value of $E_{os} = 105{,}850$.

Dividing by 100 and then squaring the real part and the imaginary part,

$$4.244\,Q^2 - 4267\,Q + 148{,}000 = 0$$

$$Q = \frac{4267 - 3961}{8.488}$$

$$= +36.0 \text{ amperes.}$$

This is plotted on Curve II in Fig. 2.

Example III

Draw the circle diagram for the same line and transformers as in Example I, except that there is to be constant voltage at both ends. This is the same as Example I, Reference 2, except that the results are expressed in amperes. The result is Curve III, Figure 2 of this paper.

Properties of the Single Conductor

New Fundamental Relations

BY CARL HERING[1]

Fellow, A. I. E. E.

Synopsis.—*The properties of a unit length of single, straight conductor, far removed from all other circuits, are investigated to endeavor to find whether such a unit is a basic, fundamental one, on which deductions and a method of mathematical treatment could be based, as was advocated by Ampere, to supplement (not to replace) the Maxwell system based on a complete circuit, and to test the correctness of some of the postulates now in common use, based on the latter system. By several new, simple, and direct proofs based only on a few well-established and accepted relations, chiefly the internal stresses in a conductor, but excluding infinities, self-inductances, induction, and any postulates, a constant is deduced for the energy stored by a current in such a unit length, which seems to be one of the most fundamental, basic constants in electrodynamics, from which many useful deductions can be made, some of which are given. This energy of the flowing current corresponds to the $m\,v^2/2$ energy of moving masses.*

Some of the results differ from those which have been in use; explanations are offered of the cause of these differences, and it is shown how the results may be brought into agreement, involving some changes in our previous conceptions. It is shown that with flux lines a distinction ought to be made which is analogous to that which distinguishes the wattless ampere from the one in phase, or between a true resistance and an impedance; it is shown why what might be called wattless flux, ought to be recognized. It is shown that self-inductance is used in two senses which may sometimes lead to different results, and that a distinction should therefore be made between them somewhat analogous to that between resistance and impedance or reactance. This it is believed would clear up the ambiguity now existing in that term. It is believed that some of these results could not have been obtained from the Maxwell complete circuit system, which rather leads one away from them.

* * * * *

Introductory

In science, as in engineering and mathematics, it is always desirable to have two independent methods of getting a result; they not only afford a very desirable check on the result and on each other, but each one often has advantages over the other in the different fields for which it is best adapted. For the analytical treatment of electric currents and circuits, the "complete circuit" system of Maxwell has been taught universally and exclusively and for so many years that the strong though wrong belief has arisen among many that it is the only possible one, and that every case must be treated from that and only from that standpoint. In some cases this has not only misled us but has sometimes even led us away from useful facts and relations.

There is a second and older system, the one advocated by that great mathematical physicist Ampere, which is based on the single conductor, and which has many advantages over the other in specific fields for which it is better adapted. Neither system should be used to completely replace the other; they should be used to supplement each other, each in its own field. An electron may start from rest, move to another point and come to rest again there, as in a bolt of lightning; while moving, it is a current and generates a magnetic field in which energy is stored, quite analogous to the $m\,v^2/2$ energy stored in a moving body. The "complete-circuit" system is a misfit in such a case and involves complications which are burdensome and confusing to the student, while the single-conductor system applies directly.

1. Consulting Engineer, Philadelphia, Pa.

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On the other hand the complete-circuit system lends itself well to integrations around a completed path. It has served its purpose well and is very useful, and in most of the usual circuits it is quite reliable. But in a search for the true, basic, fundamentals, there is no such a thing as a fundamental or unit or limiting circuit; the nearest approach to one is a circular circuit in the form of a tore or torus whose centerline radius is equal to the radius of the wire, like a doughnut with an infinitely small hole through it. This is the shortest circuit which can be made with a wire of given diameter, hence is at least a limit, but for various reasons this is not satisfactory as an ultimate fundamental.

The writer has therefore concluded that the only real fundamental is a unit length of a long straight, single, conductor, far removed from all others, as this embodies absolute ultimata; it is the form which is most free from all external influences, and besides the current, it involves the least number of variables, in fact only one, the radius of the wire, and even that one falls out in some cases, as will be shown below, for relatively to the infinite free space around it for the magnetic flux, the small finite radius of the wire becomes negligible.

The purpose of the present paper is to examine analytically the properties of such a unit length of this fundamental conductor, without involving infinities, the limitations of complete circuit mathematics, self-inductances, induction, postulates, or any but well established relations, and to deduce from these properties any useful relations and constants that may exist.

To do so by considering a straight line as a special case of a circle of infinite radius, is unsatisfactory, as it introduces that dangerous quantity, infinity, with its serious pitfalls into which many otherwise able men

have fallen[2]. In a French book by Fleury dealing with infinity he says: "Infinity has no other property than that of being impossible. Any calculation based upon absolute infinity, or upon any function whatever of absolute infinity, is itself absurd." The writer agrees with him in this, in part. When the results of two methods fail to agree, "look for the infinity" he says, and you will probably find the error.

When absolute infinity occurs, as it does, in mathematical deductions, there are two ways in which it can be safely applied in practise. The first one applies (as Fleury admits), when it is possible to assume that the quantity is simply so large (though finite) that others which depend on it may safely be taken as the same as they would be if it were infinitely large; this is often the case. For instance, in starting a current in circuits containing some small inductance, a few seconds is generally quite safely taken to be the equivalent of the eternity required theoretically for the current to reach its final value even in very accurate tests; the currents in even sensitive tests made in New York do not appreciably affect simultaneous researches made in Philadelphia, the 90-mile distance being practically infinite. Our atmosphere should extend theoretically to infinity, according to the laws of gases, yet beyond the relatively short distance of 50-60 miles there is not enough left to consider; the moon, sun, planets and stars encounter no friction in our atmosphere, even though it should extend theoretically to infinity.

The second one applies when some *property* of an infinite quantity can be found which is finite and therefore can be practically applied; thus the 760-mm. pressure of our atmosphere is finite, though according to the theory of gases, the atmosphere must extend to infinity; or similarly, the radial magnetic pressure on the surface of a single straight conductor, by the flux surrounding it, is known to be finite, although the flux, like the atmosphere, should extend theoretically to infinity. It will be shown later that under certain conditions the flux energy is also finite, though the flux is infinite.

One of the pitfalls in dealing with infinities obtained mathematically is that sometimes the real result is that the quantity is merely indeterminate and not infinite; this may arise when a factor has been suppressed or dropped because it is unity, but it is physically still present.

By treating the circle as a special case of a straight line, instead of the reverse, infinities and their pitfalls are avoided, which is another reason for preferring to start with the straight line as the fundamental.

The Single Conductor

In dealing with the single straight conductor as the fundamental, the real underlying condition (besides the straightness of a reasonable length) is not that it must be infinitely long, but merely that the unit length is assumed be so far removed from all other currents, or magnets, that they will have no appreciable effect on it; such currents include its own return circuit. Hence in a complete circuit in the form of a large square the sides may be made so large that a unit length l, Fig. 1, in the middle of a side, is no longer affected by the return current in the opposite side L.

The only three effects which neighboring currents can have on the unit length l, are attraction, repulsion and induction, which decrease as the square of the distance, and although they may also increase as the length L increases, yet the action of both combined is always a *decreasing* function, hence a distance may always be reached at which the effects are small enough to be neglected, as is always done when two or more independent tests with complete circuits are made at different places at the same time, even though with great accuracy.

Hence such a square can always be conceived in which the field at its center may safely be taken as

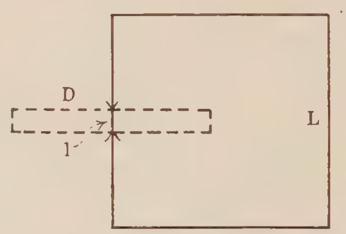

Fig. 1

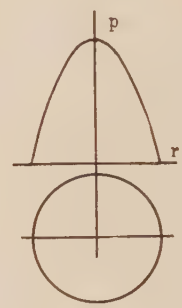

Fig. 2

zero, and therefore a unit length l in the middle of a side is practically as free from the effects of neighboring currents, as though it were a single conductor, and the flux and flux energy inherent with it are practically those in the disk-shaped space D between two parallel planes one unit apart, just as they are in a single conductor. Such a unit length l may therefore be taken to represent a unit length of a single conductor to any degree of accuracy desired by merely making the square large enough. Such a square circuit is therefore a connecting link between a unit length of a single, straight, conductor and a complete circuit; and the condition of infinite length, so often used in order to degenerate the single conductor to the realm of impossibilities, is no longer justifiable; some of the pitfalls of infinity are thereby avoided.

Maxwell himself determined (Art. 478) the now classic law for the flux density around a single conductor, with such a closed circuit; Northrup's determination of the internal pressures in a single conductor produced by the flux, is not based on the condition of infinite length, but as he says, merely on freedom from the effects of neighboring currents, and the accuracy of his expression was checked experimentally in a

2. This was well brought out in a discussion by Dr. C. O. Mailloux, Trans. A. I. E. E., Vol. 42, 1923, p. 328, Col. 2, par. 4, to p. 329, Col. 2, par. 2.

closed circuit. Ampere's able analytical researches with the single conductor were no doubt based on the same conditions; so is the generally accepted $i^2/4$ energy of the flux in the interior of a conductor. Many other like cases could be cited, showing that the infinite length is not a necessary condition. The same condition of freedom from all external influences is assumed in all accurate electrical tests, hence it is not an unreasonable or impossible condition.

Energy

Energy is the one physical quantity which is common to all physical phenomena and processes, and its absolute unit, the erg, applies to them all; hence it is the best and in fact the only connecting link between all the different groups of physical phenomena. Forces may be electromotive, magnetomotive, or ponderomotive (tending to move masses), each of which is physically different from the other, and their units are different and are not directly convertible. Moreover some forces are vector quantities, have components and resultants, can be generated or annulled and follow different laws, while energy is always a constant quantity no matter what form it may be in and its laws are common to all its forms. Energy is therefore the best physical quantity to use as a fundamental and the best connecting link between different physical phenomena.

Zero Resistance

In searching for fundamentals the number of factors or variables should of course be the least possible. At absolute zero of temperature the resistance of pure metals is eliminated, as it is zero; a current once started, as by induction, will therefore continue (theoretically) to flow forever, just as a body set into motion will continue to move when it meets with no resistance. Zero resistance will be assumed in the present discussion.

In the electric case this stored energy, which was stored while the current was started, is represented entirely by what seem to be stresses or strains of the ambient ether, which are called magnetism, hence it is magnetic energy and seems to be very closely analogous to the mechanical stresses or strains in compressed or stretched elastic rubber, and is static or potential in its nature. This stored energy of a current is closely analogous to the $m\,v^2/2$ energy stored in a moving body. When any of this stored energy, at zero resistance, is released, as by doing external work, the current also decreases, as shown in a paper by the writer,[3] and when it has all been released the current will become zero.

Such a condition of zero resistance simplifies greatly the considerations and conception of some electrical phenomena involving flux and energy, as there is then no external source of energy to mask the conditions when some of the stored energy has been released, as is the case when a "constant current" is specified in stating the laws, as it usually is, in which case the released energy is at once restored again, and there is also a continuous flow of energy. At zero resistance and with no connected source, the variables are reduced to their minimum, hence they are the best conditions for studying the fundamentals. The permeability is, of course, assumed to be unity, in all such fundamentals.

Unit Relations

The very basis of the absolute or c.g.s. system is to make as many as possible of the numerical relations between different fundamental physical quantities, unit relations, that is, the coefficient is unity, in which, however, the factor 2 often resulting from integrations, and π which cannot be avoided, must be included. If therefore, in the search for new fundamentals and relations between them, the latter turn out to be unit relations, the presumption is strong that they are correct, though it is not necessarily an absolute proof. A number of the relations deduced below will be seen to be unit relations.

The Fundamental Constant

One of the most basic fundamental quantities in electrodynamics therefore seems to be the energy represented by, or inherent with, or stored in, a unit length of single, straight conductor by a given steady current, under the most basic conditions; if this quantity leads to unit relations its fundamental character is confirmed.

Determination of this Constant. The problem which the writer endeavored to solve therefore was to determine this basic fundamental constant and to do so by a method which does not involve any physical quantities other than energy, mechanical forces, and currents, hence excluding completely that ambiguous quantity called self-inductance, and the theory of linkages (perhaps still incompletely proved) in the case of self-produced flux, both of which are so often relied upon absolutely in such energy calculations; nor does it involve any infinities or "postulates"[4] and it is moreover very direct and simple; there should, therefore, be no difficulty in either confirming it or pointing out precisely the error in it, if there is one. This energy should of course be the same no matter by which process it has been determined; if not, an explanation must be looked for and it ought to be possible to find it, especially if it lies in this simple proof. Fleury's advice in such cases is to "look for the infinity." While this method is new and different from the orthodox ones, it involves no new or unproven laws.

The method is based on the recently discovered and now well-known fact that when a current passes through a conductor internal stresses and strains in the form of radial pressures and longitudinal tensile stresses are produced, quite analogous to those in a magnetic field;

3. Trans. A. I. E. E. Vol. 42, 1923, p. 325.

4. A postulate is defined in the dictionary as "a proposition accepted *without proof;* something that must be *assumed* in order to account for something else." (Italics are the author's.)

but as the former act directly to tend to move the material of the conductor, they produce truly ponderomotive forces (tending to move masses), as is readily shown when the conductors are liquid and the current is large enough, as they increase with the square of the current, like most other electromagnetic forces. Being true mechanical forces they can be correctly specified and measured in dynes. Hence by letting these known mechanical forces act through known distances, the corresponding amounts of energy may be determined. Unfortunately neither Ampere nor Maxwell had the advantage of any knowledge of these internal stresses.

Internal Stresses

Many years ago the writer noticed these stresses when large currents were passed through liquid conductors in electric furnaces; the forces were sometimes strong enough to completely rupture the circuit by crushing it radially or tearing it longitudinally, and as this always occurred in one place by depressing the liquid where the cross section of the open channel happened to be least, the phenomenon was colloquially called the "pinch effect" by which term it is now generally known. These forces are now used very effectively in hundreds of electric furnaces for lifting and circulating the liquid metal.

Later, Dr. E. F. Northrup, to whom the writer had described this peculiar phenomenon, developed the mathematical formula for the quantitative value of these pressures, in a very able paper.[5] He based it on the attraction of the filamentary conductors for each other, and also on the radial force acting on each filamentary conductor due to its being in the magnetic field inside of the conductor; both methods gave the same result. It is important to note that it was also confirmed by him later experimentally to a high degree of accuracy (using, of course, a complete circuit), showing that the pressures were true, mechanical ones, and that their units in the formula are in dynes per sq. cm. This formula or law may therefore be safely accepted as quantitatively correct, reliable and accurate. The present writer showed later that in the c. g. s. system this law is a *unit relation* for the pressure at the center of a round conductor which, though it may not be a proof, is always strongly confirmatory of correctness. This easily remembered relation is $p = i^2/S$ in which S is the section.

Northrup's general law for the radial pressure p in dynes per square centimeter at any point in the interior of a round conductor of radius R at a radial distance r from the center, and carrying a current i, is $p = i^2 (R^2 - r^2) \div \pi R^4$, the now well-known "pinch" pressure formula; all the quantities are in c. g. s. units. This gives the *mechanical* stresses or strains in the form of radial pressures in any part of the cross section of a round conductor, produced by a current flowing through it. The curve of these pressures is a parabola, Fig. 2; hence for the whole section the curved surface of the loci is a paraboloid of revolution. This mechanical pressure is zero at the circumference, a maximum at the center, and the mean over the whole section can readily be shown to be half of the maximum; the formula also shows that this radial pressure is independent of the length of the conductor. This formula is based on the condition that, as Northrup himself states it, the conductor is a part of a very long straight conductor of circular section "very far separated from its return conductor," hence is not limited to the impossible infinitely long conductor.

5. *Physical Review*, June 1907, p. 474.

Proofs

There are several proofs of this constant, $i^2/2$ ergs per cm. all of which lead to the same result and therefore confirm each other. They are rigid, being free from approximations, dropped factors, infinities, inductance, self-inductances, or mere postulates. One is based on the radial pressures, one on the longitudinal force, and other shorter ones based on what some may consider allowable assumptions. The energy referred to is that which is required to start a steady current; it is constant while the current is flowing, and is set free again when the current stops; it is quite independent of the energy which may be transmitted while the current is flowing; it is quite analogous to the vis viva or the $m\,v^2/2$ energy in a moving body, like that required to bring the cable itself up to its normal speed in a cable transmission. By the first method, based on the radial pressures, it is measured as it is set free, while the current decreases to zero; it involves only two of Maxwell's undisputed laws. By the second method, based on the longitudinal force, it is measured as it is being stored by a constant current in an increased length of the conductor; it involves only the Northrup and the so-called Kelvin laws. In both, the conductor is assumed to be a liquid, and the energy is measured by the mechanical work done by this energy.

Radial Pressure Method. A steady current is assumed to have been started by an external source, in a circuit of zero resistance, hence would continue to flow without a connected source until all its vis viva or stored energy has been consumed by transformation into some other form of energy. This stored energy is quite analogous to the $m\,v^2/2$ energy stored in a body moving at a constant velocity and without encountering any resistance.

An experimental proof that the energy stored in a body moving at a constant velocity is equal to that given by the well-known formula $m\,v^2/2$, might be obtained by opposing the motion of that body by a *constant* pressure or force until it comes to rest, when its energy is exhausted; then the product of this force and the distance over which it was applied before the body came to rest, would evidently be equal to this

$m\,v^2/2$ energy, thereby proving that this expression gives the correct amount, or that this amount might be determined in that way if that formula were unknown.

The present method is quite similar. Assume any given length l of such a straight, single, liquid conductor of circular section having a radius R and a current I (c. g. s. units); or it may be the whole circuit of length l, if only it is large enough that each unit length is far enough from the return circuit not to be affected by it. It is well known and could easily be shown, that such a liquid conductor will tend to shrink radially, due to the pressures produced by this stored magnetic energy.

From Maxwell's $H = 2\,I/R$ for such single conductors, and his $H^2/8\pi$ pressure formula, this radial magnetic pressure on the outside surface is easily shown to be $I^2/2\pi\,R^2$ in dynes per sq. cm.; this is the total, *resultant*, pressure; it will be explained below why this is the resultant and under what conditions Maxwell's $H^2/8\,\pi$ pressures are true mechanical pressures in dynes per sq. cm. Whatever may be the detailed explanation of the mechanism of this shrinkage, say through a radial distance d, it is true in any case that this pressure must have then acted through this distance d and has thereby done work. Let the outflow of this liquid due to this shrinkage be assumed to be opposed by a constant mechanical pressure on the liquid (analogously to the constant pressure referred to above opposing a moving body), as for instance by making the liquid which is ejected by this shrinkage raise a weight, as it does in hundreds of electrical furnaces in daily use.[6] This opposing constant outflow pressure is made equal to the above radial pressure.

In thus acting on the outside through the distance d this constant radial pressure has set free a known part of the energy originally stored in the flux; this is determined from the distance d and the known force, equal to this constant pressure multiplied by the mean area. Hence there is then left less flux energy and therefore of course also less current. Let this shrinkage at constant outside pressure against an equal, constant, outflow pressure, continue until the conductor has shrunk to a line, that is, to zero.

At these radial and outflow pressures, assumed to be constant and equal, it can be shown that $I^2/i^2 = R^2/r^2$ in which i and r are the current and radius after a shrinkage; for the first pressure P is $I^2/2\,\pi\,R^2$ and the pressure p after this shrinkage to a radius r is $i^2/2\,\pi\,r^2$; when these are made equal to each other the above relation follows. Hence $I/i = R/r$, that is, the currents will diminish in proportion to the radius, and therefore the current, and with it of course the energy also, will become zero, when the radius has shrunk to zero. This shows that *all* the stored energy has thus been consumed in crushing the conductor to zero. The remaining energies are proportional to the squares of the currents or radii, but this is not an essential relation in this proof.

It also follows that for any given length l of the conductor the total radial *force*, as distinguished from pressure (force = pressure $\times$ area), diminishes in proportion to the radius, that is, $F/f = R/r$ and it is therefore also zero when the radius is zero. These simple relations hold only when the outflow pressure is made numerically equal to this constant radial pressure; this outflow pressure always exists at a distance from the center equal to the outside radius divided by the square root of 2, as shown by the Northrup formula, and his experimental demonstrations show that these forces are true, mechanical forces in dynes agreeing quantitatively with Maxwell's formulas.

As the original radial pressure is $P = I^2/2\,\pi\,R^2$ the force at first is $F = 2\,\pi\,R\,P\,l = l\,I^2/R$ in dynes, and as it diminishes in proportion to the radius, the work done by its acting radially to the center is the mean of the original and zero, hence is $l\,I^2/2\,R$, which acting through the distance R gives as the original stored energy $W = l\,I^2/2$ ergs or $I^2/2$ ergs per cm., *which is the basic, fundamental constant sought for.* This quantity was thought by our forefathers to be infinity, as deduced from the "complete circuit" system; the explanation why there is this disagreement will be given below. Attention is called to the fact that this total $i^2/2$ ergs, is just twice that long known to reside in the inside of the conductor.

The same result could be obtained by the calculus, and the liquid might then be assumed to be ejected continuously at the center where the pressure will vary from twice the radial pressure at the start, to zero at the end; the opposing outflow pressure must then be assumed to vary accordingly in order that at every moment there is equilibrium. The radial pressures will then no longer be constant but will decrease, and the current will decrease faster than in proportion to the radius. It is then analogous to stopping the movement of a body by means of a variable, instead of a constant, force.

Longitudinal Force Method. A steady current is assumed to be kept flowing in a liquid conductor of zero resistance, zero weight, and constant diameter, by a continuously applied source. Instead of allowing the mechanical stress to act radially to set free the stored

6. If necessary to picture the details (though they are immaterial and do not affect the theory involved) let the liquid be supposed to be ejected through a tube leading to a cylinder foreign to the conductor, having a piston which raises a constant weight; as the pressures in the interior of the conductor are known to be different at different distances from the center, this tube is assumed to be applied at that radial distance r from the center (namely when $r^2 = R^2/2$) at which this particular pressure exists and is constant during the shrinkage, hence it must be assumed to be moved toward the center as the conductor shrinks. When this is done, and only under those conditions, the quantitative mathematical relations become extremely simple, as will be shown. This shrinkage against an opposing pressure must of course be assumed to take place simultaneously throughout the whole of that circuit, though only a portion of it needs to be considered mathematically.

energy as before, it is now allowed to act longitudinally to lengthen the conductor of constant diameter by a specified amount, whereby the source adds to the circuit the energy stored in this added length. This added energy is calculated by letting this known longitudinal force lift a known weight through a known height while lengthening the conductor by the latter distance; the source thereby does a known amount of external work, and according to the so-called Kelvin law it then simultanously adds to the stored energy of the circuit an amount equal to the external work done. Hence the energy stored in this added length is equal to this known external work done.

The force is calculated from the pressures given by the Northrup law, which is generally recognized as correct, both relatively and quantitatively, and the pressures have been shown experimentally to be true mechanical pressures in dynes per sq. cm.; it may now be safely classed under the "classic" laws. The

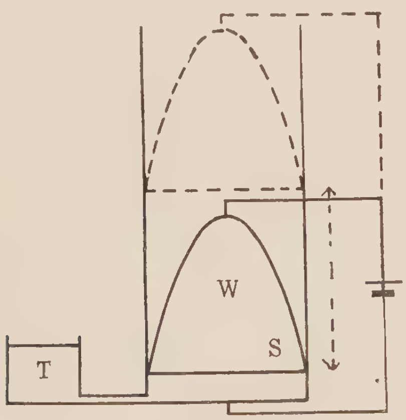

FIG. 3

Kelvin law, though not always referred to by this name, seems to be a universal law in dynamics and when properly worded, may also be safely classed under the "classic" laws. The conditions of the circuit are that only the additional length need be liquid, the parts near it must have the same diameter, the part that moves must be considered as weightless and of course it must be straight for a reasonable length and the return circuit must be far removed.

In Fig. 3, let S be conceived to represent an infinitely thin cross sectional layer of a circular, liquid, conductor of radius R. Let W be a weight, which may be shaped as a paraboloid of revolution to correspond with the pressure loci in Fig. 2, though merely to simplify the conception, as a cylindrical body of half the maximum height and the same base, would have the same weight or volume and would answer quite as well. Let a current i be conceived to be passed axially through this section, the rest of the circuit being shown diagrammatically only. Let the layer S be assumed to be connected at its circumference, where the pressure is zero, to a supply reservoir of more liquid diagrammatically represented by T; the liquid is assumed to be weightless and the supply from the outside is assumed to exert no pressure and to involve no energy.

The conductor S being a liquid the radial pressures of the Northrup formula will act equally well axially, let it be said by hydraulic action, if that is preferred; hence they will raise the weight W, the additional weightless liquid necessary to provide for the lengthening of the conductor, being supposed to be supplied from the outside under no pressure. The pressure formula will be seen to be independent of the axial length, hence these axial pressures will always remain the same as the weight is raised, that is, the total vertical lifting force is a constant, for a constant current. This axial lifting force is being used in hundreds of electrical furnaces in daily use lifting many tons per day, hence is well known and not a mere theoretical force on paper; its quantitative value is also well known.

Let the weight be lifted l cm. (Fig. 3). The surface of the loci of the pressures being a paraboloid of revolution, it can readily be shown[7] that the average pressure over the whole section is half the maximum at the axis. At the axis $r = 0$ (in the Northrup formula), hence the maximum pressure there is $p = i^2/\pi R^2$; multiplying half of this by the total area πR^2, gives $i^2/2$ as the force in dynes; that is, the total lifting force, and therefore the weight W which it will lift, is numerically equal to $i^2/2$ dynes. Having lifted it l cm. the external energy expended on the weight is: energy = force $\times$ distance $= l\, i^2/2$ or $i^2/2$ ergs per unit length. Hence according to the above mentioned Kelvin law, the stored magnetic energy of the conductor per centimeter of length, must be $i^2/2$ ergs also, the source having supplied double this energy. *This is the basic fundamental constant sought for.*

Other proofs. A given radial pressure can always be replaced by its corresponding circumferential tension. If P is the radial pressure on the outside of a conductor as given above, it can be shown that the tensional force (not pressure) in a band encircling a unit length of the conductor and producing the same radial pressure, is $P\,R$ in dynes, in which R is the radius. If a stretched, elastic band, having this tension be assumed to be developed into a straight line (equal to the circumference) and then allowed to shrink to zero length, following the law of the perfect spring, namely that the tension is proportional to its length, it can be shown that the energy set free thereby is again the same, $i^2/2$ ergs.

From the Northrup formula the pressure in dynes per sq. cm. at the center is just twice the $i^2/2\,\pi\,R^2$ pressure in the same units, at the periphery, from outside. As the outside pressure must also act at the center, it might be argued that the inside flux has added an equal amount, hence that the energies residing inside and

7. It is well known that the volume or weight of such a paraboloid of revolution is equal to that of a cylinder having the same base and half the height.

outside are equal, therefore the total is double the well known inside energy $i^2/4$.

At the periphery the two mechanical forces balance, as there is no tendency to movement there, according to the Northrup formula; there is no resultant there. As the forces are equal the energies should be also, as both forces must be considered relatively to the same center, hence as acting through the same distance, the radius. Again the total is twice that inside.

The very basis of the c. g. s. system is that the fundamental relations are unit relations, at least as far as possible. If it may therefore be assumed that the self-inductance (in its true, energy sense) of a unit length of the fundamental conductor, is unity, then if L in the usual expression $L\,i^2/2$ for this energy, is made unity, the energy becomes $i^2/2$. A self-inductance is stated to be physically a length, and in the c. g. s. system it is correctly measured in centimeters. Under fundamental conditions this length and the length of the conductor should be the same thing. This constant then follows directly.

Those who recognize the existence of the longitudinal force, will find that in a fundamental conductor of uniform diameter it is numerically equal to $i^2/2$ dynes, from the Northrup formula, and that in this fundamental conductor it is independent of the diameter or the length. Hence when this force acts to stretch or lengthen its conductor without doing any external work, (though generating a counter e. m. f.) the energy is being stored, just as it would be when the speed of a moving body is increased. If l is this added length, the added energy will of course be $l\,i^2/2$ ergs, which for a unit length again gives $i^2/2$.

Doubtless still more proofs could be found which are also free from the pitfalls of infinities, the ambiguous self-inductances, and the short comings of the complete circuit theories, which had misled us in the past.

Deductions from this Constant

It will be seen that this constant is independent of the diameter of the wire, and depends only on the current, both of which have long been known to be true of the flux energy residing in the interior of the conductor, $i^2/4$. For any length l the energy is $l\,i^2/2$, that is, it is directly proportional to the length. This $i^2/2$ ergs is apparently one of the most basic fundamental constants in electrodynamics, and from it interesting deductions follow.

This $i^2/2$ is the total stored energy, outside of the wire and inside. It has long been known and is easily proved, that the amount stored inside of the conductor is $i^2/4$ ergs per cm. It follows therefore that of the total, half of the energy resides in the inside and half on the outside, as one might expect nature to distribute it.

This constant also shows that the energy of the flux is finite, though the flux itself is of infinite extent, in the same sense that our atmosphere extends to infinity. It is one of those cases in which a *property* of an infinite quantity is finite and therefore affords a means of treating an infinite quantity mathematically without danger of falling into the pitfalls of mathematical infinity. Another finite property of this theoretically infinite flux is what might, in a certain sense, be called the resultant or equivalent flux, as will be described below.

Reduced to the units used in practise the general formula becomes $W = 0.00001524\ l\,I^2$ in which W is the stored energy in watt-seconds or joules, l is the length in 1000-ft. units, and I is the current in amperes. This shows how extremely small it is.

A very interesting and important deduction, showing another new unit relation, is that in the c. g. s. system each unit of current generates one unit of flux around such a conductor, in each unit of length, and independent of the diameter; it includes all the flux inside and outside. But this flux must be specifically defined, as it is a resultant, equivalent, or condensation of all the very large number of lines into which it divides itself as it spreads out into space; these resultant lines might be termed fundamental maxwells. This condensation is such that these resultant lines when combined with the magnetomotive force in common to them all, represent the true stored energy in that field. It is somewhat analogous to supposing our widely diffused atmosphere to be condensed into a thin solid or liquid layer around the earth, which has the same mass. Or these condensed lines may be imagined to be those originally generated by the current and then spread out into space according to the laws of distribution, *but without any change of energy contents*, just as the condensed atmosphere would spread out without change of mass. Such lines are a means of summing up an infinite quantity by one of its properties (energy in this case) to get something finite. They are useful in calculations of flux energy and they clear up some ambiguities, but they are sometimes distinctly different from those entering into calculations of the induction of e. m. fs. by cutting or linking. This will be further discussed below.

The proof of this equality is as follows. The energy residing in a complete circuit of flux is: ergs = maxwells $\times$ gilberts/$8\,\pi$. The magnetomotive force in gilberts around a single conductor is $4\,\pi\,i$, and as the energy per unit of length is $i^2/2$, it follows that $i^2/2 = 4\,\pi\,i\,f/8\,\pi$ in which f is the number of lines in maxwells; hence $i = f$. This unit relation is a fundamental one and applies rigidly only to the fundamental conductor, and of course, not at all to bi-filar non-inductive circuits, nor when the permeability is not unity. The "complete circuit" mathematics leads us away from it rather than toward it. It seems to mean that in the c. g. s. system current and flux are merely different physical representations of the same quantity, as far as energy is concerned, though, of course, only when the resistance energy is zero; or that magnetism

is merely an effect of current at a distance, the energy residing in the moving electrons.

For a unit length and unit radius the total radial force (not pressure) from the outside, is numerically equal to i^2 dynes, hence is another unit relation; for other radii it is inversely proportional to the radius. This force multiplied by half the radius (because it is radial) again gives the constant $i^2/2$.

The stored magnetic energy in any part of a circuit is generally calculated from the formula $L\,i^2/2$ in which L is the self-inductance of that part in centimeters. In the fundamental conductor this energy is $l\,i^2/2$ in which l is the length in centimeters. Hence in such conductors the self-inductance (in the energy sense of that term) is the same thing as the length of the circuit, that is, the distance over which the current flows; another interesting unit relation. This explains why a self-inductance is physically the same kind of a quantity as a length, a purely geometric quantity, at least under the most fundamental conditions; the permeability is of course taken to be unity in all fundamental cases. It also shows why in the c. g. s. system it is correctly expressed in centimeters, or in 10,000. kilometers for the henry. It also follows that under these fundamental conditions the self-inductance is independent of the diameter of the wire, which would seem to follow also from the long-known fact that the energy of the flux in the interior of the wire is independent of the diameter.

This stored electromagnetic energy, $l\,i^2/2$ of a current is quite analogous to the visviva or stored mass energy $m\,v^2/2$ of a moving body. In the c. g. s. system both are equal to ½ erg when all the quantities are unity, and one may write $l\,i^2 = m\,v^2$, which means that if all the electromagnetic energy stored by a current i flowing for a distance l, in such a single conductor, be converted into moving mass energy, the relation of the mass to the velocity must be such that $m\,v^2 = l\,i^2$. Thus for say 1000 amperes flowing in such a conductor, the stored electromagnetic energy in every foot, is the same as the mechanical energy stored in a weight of 0.723 or nearly ¾ lb. moving at 1 ft. per sec., or 0.181 lb. at 2 ft. per sec.; all are equal to 0.01124 foot-pounds or 152,400 ergs. This is the energy, per foot of conductor, set free when the current is stopped. For any other length of conductor this equivalent mass increases as this length.

It is of interest to note that for 1 ampere this energy stored per centimeter is equal to that of 5.10 millionths of a gram raised one centimeter, which is extremely small, and shows why the least resistance in such a conductor stops a current almost instantly after the e. m. f. ceases. Yet our forefathers claimed that this energy was infinitely large, which it seems is still being taught.

Another result which this constant, $i^2/2$, has led to, is a better understanding of the true nature of flux energy and calculations pertaining to it, as explained below.

Disagreement

When this stored magnetic energy per unit length of a single conductor is deduced by means of the mathematics of the complete circuit and by some of the older methods and postulates, or by means of self-inductance formulas (always only approximate), the result is that even for a very small current this stored energy per unit length is infinite, while $i^2/2$ is generally quite small. But as the above proofs are simple, brief, rigid, and involve nothing but well established laws, it does not seem possible to find any error in them in a long discussion since the writer's first publication of this result,[8] deduced by a similar though more involved process.

The discrepancy therefore must be looked for elsewhere. The mere fact that the result differs from our older views, cannot of course, be accepted as a proof of an error in it; if that were done in this and other cases, further progress in science would be checked.

The writer believes that this discrepancy can best be located and explained, and that the criticisms of the above proofs can best be answered, by first getting a clearer conception of the various factors and elements involved, and by endeavoring to show how and where some of our older conceptions had misled us, and which of them may be questioned and should be modified or revised if wrong. The new result, if correct, may well be used as a test of the correctness of some of the older laws and postulates.

These explanations are discussed in detail in the complete pamphlet copies of this paper; the following is merely a very brief synopsis. If in the large square circuit Fig. 4, the lengthening (in the second one of the proofs) takes place in both of two opposite sides, the only new flux will be in the parts D, D, and that in the rest of the circuit will not have been changed in the least. This answers some criticisms concerning the "rest of the circuit." If instead, such a circuit be

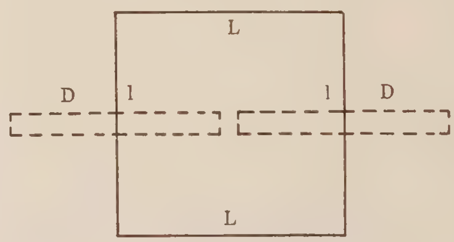

Fig. 4

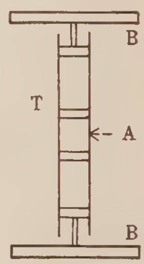

Fig. 5

forced to be shortened slightly instead of lengthened, it must set free an infinite amount of energy, according to the ideas of our forefathers; but this is evidently absurd.

Fig. 5 illustrates the same principle as that involved in lengthening a rope supporting a weight; the force in this additional past must not be added to that in the rest as it is the same force. This answers a criticism.

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8. A Single Straight Conductor as a New Fundamental. *Jour. Frank. Inst.*, Feb. 1925, p. 235. In this article the first part of the paragraph forming the upper half of p. 243 contains an unfortunate arithmetical error and should be deleted.

In Fig. 6, if C is the cross section of a conductor the curve F gives the density H outside of the wire, and f that inside; at the surface they are both equal to h. The flux lines outside act by their contraction like layers of stretched rubber bands over each other; hence the radial pressure at the surface is the *resultant* of all those radially beyond; just as the 760 mm. pressure of our atmosphere is the resultant of those of all the layers above. In either case it would be wrong to add to this resultant (as by integration) the pressures of its component parts beyond; or to add the energies based on these pressures, yet this has been done by our forefathers. This is claimed to have been the chief cause of the disagreement.[9] Zero resistance should be assumed in such cases, as energies which are set free are then not continuously being restored. Although the outside and inside flux pressures balance each other at the surface where they are h, it is explained how the outer one will act when the inner mechanical pressure is reduced.

In Fig. 7 C is the section of a very thick walled rubber tube, expanded by a compressed liquid h. The stresses, strains and stored energy in this rubber wall are then closely analogous to those in a magnetic field around a conductor h. In both, the radial pressures on h are the *resultants* of all those radially beyond, which must therefore not be added to them; the energy stored in the rubber is finite, and could be measured by allowing the liquid to be ejected under pressure, as in the first of the above proofs. Flux lines exist in the space around the wire, but if the energy of the whole field has been determined from their resultant at the surface, those beyond must be considered as wattless, in the sense that their energies have already been accounted for in their resultant and must therefore not be added to it again. It is shown that the e. m. f. induced by cutting or linking of lines is independent of the energy residing in those lines, which may therefore be wattless in the above sense; hence the energies in such lines cannot be deduced from the e. m. f. induced.

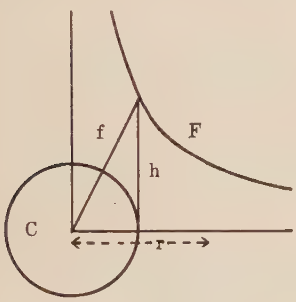

Fig. 6

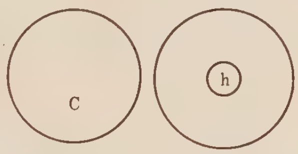

Fig. 7

It is shown that Maxwell's $H^2/8\pi$ pressures are true mechanical pressures in dynes per sq. cm. when properly interpreted. This expression seems to apply correctly only to uniform fields, hence not to those with curved lines, as in these some of the pressures are the resultants of others; or it may be applied to differentially small parts, but can then not always be added together by integration. The lack of consideration of the abutments of the forces, has led to confusion; they do not appear in calculus calculations and are often overlooked. The ether cannot act as an abutment for mechanical forces. The abutment of the encircling flux is the surface of the wire.

The propriety of using the term self-inductance in both of its two different senses (inducing e. m. fs. and determining the stored energy) is questioned. It is shown that the error of adding the energy of components to that of their resultant, enters. As all self-inductance formulas are only approximate, extrapolating them to infinity is not rational, yet it has been done. Self-inductance is generally defined as a derived quantity, flux per ampere, yet physically it is a mere geometric, independent quantity, a length, hence independent of either flux or current. That ratio may sometimes lead to errors when some of the flux should be considered as wattless just as a resistance defined as the quotient of volts divided by amperes, may lead to errors when some of the amperes are wattless. Reforms in the true meaning of the term self-inductance are recommended and reasons are given.

The error arising from adding components to their resultant, seems to be greatest for very large single turn circuits, and small for the coils used in practise; still less when iron is used, as is usual. It affects theory, especially basic fundamentals, rather than practise. Attention is called to the much discussed longitudinal force and its evident existance in this investigation; its value is given.

Conclusions

In the opinion of the writer, the above proofs, deductions, and discussion, will show that a new system of treatment of electrical problems can be based on the single, straight, conductor, as distinguished from that based on the Maxwell complete circuit; not to replace the latter system but to supplement it, and to test the correctness of parts of it. The single conductor system leads to some new and useful results and shows that we should modify some of our former conceptions; also that in flux lines there is an analogy to the wattless ampere which ought to be recognized. It also shows that the term self-inductance has been used in a dual sense and that a distinction should be made analogous to that between resistance and reactance. Some heretofore unknown and useful relations have been deduced from what is believed to be one of the most fundamental constants in electrodynamics, the value of which is determined by simple proofs. Some of the results deduced could not have been deduced from the complete circuit system, which has, in some cases, been misleading.

9. This is also discussed in an article by the writer on Magnetic Flux Energy, in the *Jour.* Frank. Inst., Dec. 1925, p. 747.

Parameters of Heating Curves of Electrical Machinery

BY VLADIMIR KARAPETOFF[1]
Fellow, A. I. E. E.

Synopsis.— *When a body is being heated by a uniform addition of a constant quantity of heat per unit time, its temperature above the ambient air (the latter being assumed to remain at a constant temperature) increases approximately according to an exponential law. The exponent is proportional to the ratio between the heat capacity of the body and the coefficient of thermal dissipation into the surrounding medium. In a paper read before the Institute's Midwinter Convention, 1925,* (JOURNAL, *Vol. 44, p. 142) Doctor A. E. Kennelly has proposed to include such a coefficient among other characteristics of an electrical machine. In the present paper it is pointed out that for thermal purposes an electrical machine cannot be considered as a single body, since the stator consists of two metal bodies (the winding and the core) between which there may be a considerable heat interchange, and that the rotor is also such a composite body. Differential equations of heat flow in a combinational body are established and solved. The stator winding is thermally determined by its heat capacity and its heat dissipation coefficient, and so is the stator core; further, there is a coefficient of mutual flow. The rotor also requires five similar coefficients. Thus, while an electrical machine could be defined by its thermal coefficients, and the temperature rise of the different parts predicted for a given operating regime, the number of required parameters is much larger than for a single body.*

* * * * *

WHEN an attempt is made to represent, analytically, the temperature rise with the time in an electrical machine at constant losses, the time-temperature curve is usually assumed to be exponential.[2] Recently, Dr. A. E. Kennelly has extended the treatment and has shown that the curve remains exponential even when the losses themselves are linear functions of the temperature.[3]

Actual heating curves sometimes differ materially from the simple exponential form. This can be shown by plotting the differences between the ultimate temperature and the instantaneous temperatures against time as abscissas, on semi-log paper. An exponential curve should give a straight line, and this is not always the case. The principal reason for this discrepancy is that the stator of a machine cannot be considered as one "chunk" of metal; it consists of two metal bodies, the winding and the core, between which there may be an appreciable difference of temperatures. The same is true of the rotor. In a transformer, three separate metal bodies at different temperatures may be distinguished.

It is the purpose of the following investigation to show that with two metal bodies at different temperatures, and with heat interchange between them through a layer of insulation, the heating curve for each consists of two exponential terms with different exponents. Thus, each part of a machine should be characterized by at least two composite thermal time constants, and these will represent an experimental heating curve much more closely than is possible with one thermal time constant and with a common curve for both the winding and the core.

Doctor Kennelly compares the transient period of temperature rise to a transient rise of current in a d-c. circuit containing a resistance r and an inductance L. In the latter case, the rise in current is also exponential and depends upon the time constant (L/r) of the circuit. However, a stator, or a rotor, is more nearly analogous to a system of two coupled electric circuits, in which the current rise is represented by two or more exponential terms, each with a different time constant[4].

With the notation given at the end of the paper[5],

$$p_1\,d\,t = \theta_1\,(s_1 - s_{12})\,d\,t + (\theta_1 - \theta_2)\,s_{12}\,d\,t + k_1\,d\,\theta_1 \qquad (1)$$

$$(\theta_1 - \theta_2)\,s_{12}\,d\,t + p_2\,d\,t = \theta_2\,(s_2 - s_{12})\,d\,t + k_2\,d\,\theta_2 \qquad (2)$$

These equations are similar to Doctor Kennelly's equation (**19**), and refer to the metal Parts 1 and 2 of one of the principal members of the machine respectively,— say the stator winding and the stator core. Equation (**1**) expresses the fact that the heat $p_1\,d\,t$, developed in the part 1 during an infinitesimal element of time, $d\,t$, is used up in three ways: The part $\theta_1\,(s_1 - s_{12})\,d\,t$ is communicated to the ambient air or other cooling medium; the part $(\theta_1 - \theta_2)\,s_{12}\,d\,t$ is communicated to the Part 2 of the machine, and the remainder, $k_1\,d\,\theta_1$, raises the temperature of the Part 1 by $d\,\theta_1$. Equation (**2**) has a similar meaning for Part 2, with the term $(\theta_1 - \theta_2)\,s_{12}$ considered as part of the heat input.

Dividing throughout by $d\,t$, and introducing the "deficiencies", $\delta_1 = \theta_{10} - \theta_1$ and $\delta_2 = \theta_{20} - \theta_2$, in place of the temperatures themselves, equation (**1**) becomes,

$$p_1 = (\theta_{10} - \delta_1)\,(s_1 - s_{12}) + [(\theta_{10} - \delta_1) - (\theta_{20} - \delta_2)]\,s_{12} + k_1\,d\,(\theta_{10} - \delta_1)/d\,t \qquad (3)$$

1. Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.

2. For a theory of such simple heating curves see, for example, V. Karapetoff, *Experimental Electrical Engineering*, First Edition, 1909, p. 442.

3. A. E. Kennelly, *The Thermal Time Constants of Dynamo-Electric Machines*, A. I. E. E. JOURNAL, 1925, Vol. 44, p. 142.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., Feb. 8-11, 1926.

4. G. W. Pierce, Electric Oscillations and Electric Waves, 1920, Chap. 7.

5. This notation is made to agree, as much as possible, with that in Dr. Kennelly's paper referred to above.

After the ultimate temperatures, θ_{10} and θ_{20}, have been reached,

we have, $\delta_1 = \delta_2 = 0$, and $d\,\delta_1/d\,t = 0$. Hence, for $t = \infty$, equation (3) becomes:

$$p_1 = \theta_{10}\,(s_1 - s_{12}) + (\theta_{10} - \theta_{20})\,s_{12} \qquad (4)$$

By analogy, equation (2) gives,

$$p_2 = \theta_{20}\,(s_2 - s_{12}) + (\theta_{20} - \theta_{10})\,s_{12} \qquad (5)$$

Substituting these values of p_1 and p_2 in equation (3) and in a similar equation obtained from equation (2), after reduction we get,

$$\delta_1\,s_1 - \delta_2\,s_{12} + k_1\,d\,\delta_1/d\,t = 0 \qquad (6)$$

$$\delta_2\,s_2 - \delta_1\,s_{12} + k_2\,d\,\delta_2/d\,t = 0 \qquad (7)$$

Equations (6) and (7) are simultaneous differential equations for δ_1 and δ_2, and their solution gives the desired expressions for the heating curves of the two metal parts of the stator or the rotor. To eliminate δ_2, differentiate equation (6) with respect to t. This gives,

$$s_1\,d\,\delta_1/d\,t - s_{12}\,d\,\delta_2/d\,t + k_1\,d^2\,\delta_1/d\,t^2 = 0 \qquad (8)$$

Multiply equation (6) by s_2, equation (7) by s_{12}, equation (8) by k_2, and add the three equations together. The variable δ_2 is then eliminated, and the result is

$$k_1\,k_2\,d^2\,\delta_1/d\,t^2 + (k_1\,s_2 + k_2\,s_1)\,d\,\delta_1/d\,t + (s_1\,s_2 - s_{12}^2)\,\delta_1 = 0 \qquad (9)$$

The solution of this equation is of the form

$$\delta_1 = A_1\,\epsilon^{-t/\sigma} + B_1\,\epsilon^{-t/\tau} \qquad (10)$$

where A_1 and B_1 are the constants of integration, and σ^{-1} and τ^{-1} are the roots of the "auxiliary" quadratic equation[6]

$$k_1\,k_2\,x^2 - (k_1\,s_2 + k_2\,s_1)\,x + (s_1\,s_2 - s_{12}^2) = 0 \qquad (11)$$

Solving this equation for x, gives

$$x = m \pm \sqrt{n^2 + q_1\,q_2} \qquad (12)$$

where

$$m = 0.5\,[(s_1/k_1) + (s_2/k_2)] \qquad (13)$$

$$n = 0.5\,[(s_1/k_1) - (s_2/k_2)] \qquad (14)$$

$$q_1 = s_{12}/k_1\ ;\ q_2 = s_{12}/k_2 \qquad (15)$$

Let, for the sake of abbreviation,

$$r = \sqrt{n^2 + q_1\,q_2} \qquad (16)$$

so that

$$q_1\,q_2 = r^2 - n^2 \qquad (16a)$$

Since the thermal time constants, σ and τ, are the reciprocals of the two values of x in equation (12), we have,

$$\sigma^{-1} = m + r \qquad (17)$$

$$\tau^{-1} = m - r \qquad (18)$$

The subscripts of the coefficients in equation (9) are symmetrical with respect to 1 and 2. Hence, an identical equation may be written for δ_2, and the exponents σ and τ are the same for both δ_1 and δ_2. Thus, the general expression for δ_2 is:

$$\delta_2 = A_2\,\epsilon^{-t/\sigma} + B_2\,\epsilon^{-t/\tau} \qquad (19)$$

Substituting in equations (10) and (19) $t = 0$, gives

$$\theta_{10} = A_1 + B_1 \qquad (20)$$

$$\theta_{20} = A_2 + B_2 \qquad (21)$$

Substituting the values of δ_1 and δ_2 from equations (10) and (19) in equation (6), and equating separately the coefficients of $\epsilon^{-t/\sigma}$ and $\epsilon^{-t/\tau}$, gives the following two necessary relationships between A_1 and A_2, and between B_1 and B_2:

$$A_1\,(\sigma\,s_1 - k_1) = s_{12}\,\sigma\,A_2 \qquad (22)$$

$$B_1\,(\tau\,s_1 - k_1) = s_{12}\,\tau\,B_2 \qquad (23)$$

A substitution of the same values of δ_1 and δ_2 in equation (7) will give no new relationships between the above constants of integration. Solving equations (20) to (23) as simultaneous equations, and using equation (16a), we get:

$$A_1 = [(r + n)\,\theta_{10} - q_1\,\theta_{20}]/2\,r \qquad (24)$$

$$B_1 = [(r - n)\,\theta_{10} + q_1\,\theta_{20}]/2\,r \qquad (24)$$

$$A_2 = [(r - n)\,\theta_{20} - q_2\,\theta_{10}]/2\,r \qquad (26)$$

$$B_2 = [(r + n)\theta_{20} + q_2\,\theta_{10}]/2\,r \qquad (27)$$

These values are to be used in equations (10) and (19).

As a check on the foregoing expression, let, in a limiting case, the two hot bodies be entirely independent of each other: that is, put $s_{12} = 0$. Then $q_1 = q_2 = 0$; $r = n$; $\sigma^{-1} = s_1/k_1$; $\tau^{-1} = s_2/k_2$; $B_1 = A_2 = 0$; $A_1 = \theta_{10}$; $B_2 = \theta_{20}$.

Hence, equations (10) and (19) become:

$$\delta_1 = \theta_{10}\,\epsilon^{-t\,s_1/k_1};\ \delta_2 = \theta_{20}\,\epsilon^{-t\,s_2/k_2} \qquad (28)$$

which agrees with Doctor Kennelly's results for a single hot body.

If the losses themselves are functions of temperature, so that p_1, instead of being a constant, is, for example, a linear function of δ_1, the general form of equation (3) remains unchanged, although the coefficients will have a different meaning. The same is true of p_2. Hence, the general expressions for δ_1 and δ_2 will be of the same mathematical form as equations (10) and (19), only the coefficients and their interpretation will have to be deduced anew, following the general method used above.

Practical Application of the Above Formulas

In order to apply equations (10) and (19) to a given machine, it is necessary to determine the thermal dissipation coefficients s_1 and s_2, the heat transmission coefficient s_{12}, and the thermal capacities k_1 and k_2. As a concrete example, consider the stator of a synchronous machine, and let the subscript 1 refer to the winding and the subscript 2 to the iron core. Let the machine be run at a certain load until the constant ultimate temperatures, θ_{10} and θ_{20}, have been reached

6. See any text book on differential equations, chapter on linear equations with constant coefficients.

and measured. Let the values of the copper loss, p_1, and of the core loss, p_2, be also known. Then, equations (4) and (5) contain three unknown quantities, s_1, s_2, and s_{12}. Let a heat run be made also at some different values of the losses, say p_1' and p_2', and let the final temperatures be θ_{10}' and θ_{20}'. Then two more equations, similar to equations (4) and (5), may be written, giving altogether four equations with three unknown quantities. If these quantities, determined from three of the equations, also satisfy the fourth, then all is well and an additional check has been obtained on both the theory and the measurements. In case of an unimportant discrepancy, an adjustment can be made of all or some of the quantities involved, to satisfy the four equations with a reasonable accuracy.

To determine k_1, equation (**6**) is applied to the beginning of the experimentally obtained heating curves of both the winding and the core. Namely, at $t = 0$, $\delta_1 = \theta_{10}$ and $\delta_2 = \theta_{20}$; $(d\,\delta_1/d\,t)_0$ is the slope of the curve (taken with the minus sign) of the lower portion of the heating curve where it is practically a straight line. Substituting these values in equation (**6**), we get:

$$k_1 = (\theta_{10}\, s_1 - \theta_{20}\, s_{12})/(-\,d\,\delta_1/d\,t)_0 \qquad (\mathbf{29})$$

A similar expression for k_2 may be written from equation (**7**).

Knowing the foregoing five constants of the machine, the auxiliary quantities m, n, q_1, q_2, r, σ, and τ may be readily computed from the expressions given above. After this, the parameters A_1, B_1, A_2, B_2 may be evaluated for any desired values of ultimate temperature rise, θ_{10} and θ_{20}, and equations (**10**) and (**19**) used to predict the shapes of the heating curves of both the core and the winding for any desired interval of time.

The values of θ_{10} and θ_{20} depend upon the losses in the machine. Knowing the losses p_1 and p_2, and the coefficients s_1, s_2, s_{12}, the values of θ_{10} and θ_{20} may be determined by solving equations (**4**) and (**5**) as simultaneous equations. The result is

$$\theta_{10} = \frac{p_1\, s_2 + p_2\, s_{12}}{s_1\, s_2 - s_{12}^2} \qquad (\mathbf{30})$$

$$\theta_{20} = \frac{p_2\, s_1 + p_1\, s_{12}}{s_1\, s_2 - s_{12}^2} \qquad (\mathbf{31})$$

Thus, with the aid of the foregoing theory, knowing the ultimate temperature rise at two different loads, and the initial slope of the heating curves at one of these loads, it is possible to predict the complete shape of the heating curves under any load conditions for which the losses are known.

Instead of determining, experimentally, the ultimate temperature rise at two different loads, it is also possible to use only one set of heating curves (one for the core and one for the winding), even without reaching the ultimate temperatures. In this case the unknown thermal constants of the machine should be determined by the method of least squares, to satisfy equations (**10**) and (**19**)[7]. The computations will be considerably more involved, but a heat run is saved, and the only heat run to be performed need not be continued until the stationary conditions have been reached. With very large machines, these considerations may outweigh the tediousness of extra computations.

NOTATION

- A a constant, in deg. cent.
- B a constant, in deg. cent.
- k thermal capacity of a body, in kw-hrs. per deg. cent.
- m defined by equation (**13**), in (hours)$^{-1}$
- n defined by equation (**14**), in (hours)$^{-1}$
- p heat input, in kw.
- q defined by equation (**15**), in (hours)$^{-1}$
- r defined by equation (**16**), in (hours)$^{-1}$
- s thermal dissipation coefficient, in kw. per degree centigrade of temperature difference; this coefficient includes the heat loss to the ambient medium and that to the other part of the composite body.
- t time, in hours
- x auxiliary notation for σ^{-1} and τ^{-1}, equations (**11**) and (**12**)
- δ deficiency in temperature, that is, the difference $\theta_0 - \theta$.
- θ temperature rise, in degrees centigrade, above the ambient medium.
- θ_0 ultimate temperature rise.
- σ, τ time constants of a combination of two bodies, in hours.

NOTE 1. Where the subscripts 1 and 2 are used in the text, 1 refers to a copper winding and 2 refers to the iron core separated from it by a layer of insulation. The subscript 12 refers to the heat conductance of this insulation.

NOTE 2. The fundamental units assumed in the notation are the kilowatt, the kw-hr., the hour, and the deg. cent. However, the formulas hold true with any units, provided that these are consistent among themselves; for example, the watt, the joule, the second, and a degree of any desired thermometer scale.

Some recent articles on heating of electrical machinery:

E. Hughes, (British) *Inst. El. Engrs. Journal*, 1924, Vol. 62, p. 628.

M. L. Keller, *Archiv f. Elektrot.*, 1924, Vol. 13, p. 292.

W. H. Cooney, JOUR., A. I. E. E., Vol. 44, p. 1342, Dec. 1925.

See also: R. Richter, *Elektrische Maschinen* (Berlin, 1924), Vol. 1, pp. 350 to 365.

7. V. Karapetoff, *Engineering Mathematics*, Vol. III, pp. 59-66.

Alternating Current Analysis

BY RALPH D. MERSHON

Fellow, A. I. E. E.

FOR a good many years past, I have made use of an analytic method, of solving alternating-current problems, requiring simple algebra only. Inquiry appears to indicate that it has not heretofore appeared in print, or been used by others. For most purposes, it appeals to me more than any of the usual methods. With the thought that it may make a similar appeal to others, the bases of it and a few simple applications by way of illustration are given in what follows.

Suppose we have a resistance r and a reactance x, in series; and suppose we impress upon the circuit the voltage e. The alternating voltage triangle gives us the relation:

$$e^2 = (i\,r)^2 + (i\,x)^2 \qquad (1)$$

Now though equation (1) applies directly only to a circuit in which the resistance and reactance are in series, it will also apply to a circuit made up of resistances and reactances in parallel, or to a mixed circuit of resistances and reactances in any and all possible series and parallel arrangements; *provided*, the value of r in the equation is such that its effect will be the equivalent of the combined effect of the separate resistances in the mixed circuit; and *provided*, the value of x is such that its effect will be the equivalent of the combined effect of the separate reactances in the mixed circuit. That is, for any mixed circuit there are values of resistance and of reactance, respectively, which when employed in a simple series circuit will give the same results, as to current and phase, as are given by the combined action of the separate resistances and reactances of the mixed circuit.

If we multiply equation (1) by i^2 we get:

$$(e\,i)^2 = (i^2\,r)^2 + (i^2\,x)^2 \qquad (2)$$

Broadly interpreted, equation (1) says that the square of the component of impressed e. m. f. in step with the current, added to the square of the component of impressed e. m. f. in quadrature to the current, gives a value equal to the square of the impressed e. m. f. While equation (2) says that the square of the "active power" added to the square of the "reactive power" gives a value equal to the square of the "apparent power." The method is based upon equation (2).

The only difference of phase there can be in the case of active power is that of 180 deg. That is, if we calculate the active power of any subcircuit[1] of a mixed circuit, it will either be in step with the active power of any other given subcircuit, or it will be directly opposed to it; *i.e.*, it will be either positive or negative with respect to it. Therefore, the active power components of the several subcircuits of a mixed circuit may be algebraically added. The same thing is true for the reactive power. The only case in which active power can be negative is that in which a component of generated e. m. f.—other than the impressed e. m. f., and opposed to the current—is included in the circuit or in one of its subcircuits. In the case of reactive power, however, the sign may be negative without an additional generated e. m. f., since we may have a negative—*i. e.*, condensive—reactance in circuit.

It follows, therefore, that we can lay down this general rule of procedure, applying to any circuit or any part thereof:

Calculate the active power of each subcircuit. Find the algebraic sum of the values of active power of the several subcircuits. This sum is the total net active power of the whole mixed circuit. Following a similar procedure relative to the reactive power, find the total net reactive power of the whole mixed circuit. The sum of the squares of these two quantities is equal to the square of the apparent power delivered to the circuit as a whole.

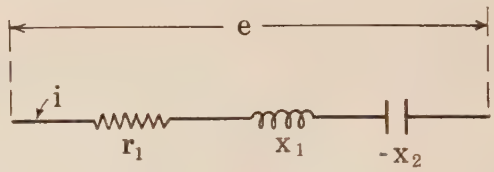

FIG. 1

By making use of this rule, alternating-current circuits may be solved by the use of simple algebra. Furthermore, only resistances and reactances, and their combinations, need be dealt with. There will be no necessity for employing their reciprocals and combinations thereof.

Applying the method to the circuit of Fig. 1, we have:

$$(e\,i)^2 = (i^2\,r_1)^2 + (i^2\,x_1 - i^2\,x_2)^2 \qquad (3)$$

From this we obtain:

$$e = i\sqrt{r_1^2 + (x_1 - x_2)^2} \qquad (4)$$

$$i = \frac{e}{\sqrt{r_1^2 + (x_1 - x_2)^2}} \qquad (5)$$

The power factor is:

$$\cos\varphi = \frac{i^2\,r_1}{e\,i} = \frac{r_1}{\sqrt{r_1^2 + (x_1 - x_2)^2}} \qquad (6)$$

1. The term subcircuit is used to indicate any one of the simplest branches of which the mixed circuit is made up. That is, a branch in which all the resistances and reactances are in series. When a circuit consists of one single series branch, then there is no subcircuit; or, the circuit is, itself, the subcircuit.

For Fig. 2 we have:

$$(e\,i)^2 = (i_1^2\, r_1 + i_2^2\, r_2)^2 + (i_1^2\, x_1^2 - i_1^2\, x_2 + i_2^2\, x_3 - i_2^2\, x_4)^2 \qquad (7)$$

But from (5) we know that:

$$i_1^2 = \frac{e^2}{r_1^2 + (x_1 - x_2)^2} \qquad i_2^2 = \frac{e^2}{r_2^2 + (x_3 - x_4)^2}$$

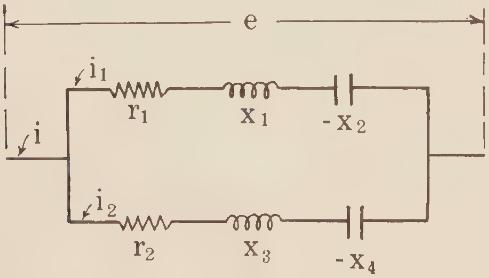

Fig. 2

Substituting these values for current in (7) and reducing

$$i = e\sqrt{\left(\frac{r_1}{r_1^2 + (x_1 - x_2)^2} + \frac{r_2}{r_2^2 + (x_3 - x_4)^2}\right)^2 + \left(\frac{x_1 - x_2}{r_1^2 + (x_1 - x_2)^2} + \frac{x_3 - x_4}{r_2^2 + (x_3 - x_4)^2}\right)^2} \qquad (8)$$

The power factors of the whole circuit, the upper subcircuit and the lower subcircuit are, respectively:

$$\cos\varphi = \frac{i_1^2\, r_1 + i_2^2\, r_2}{e\, i} = \frac{\dfrac{r_1}{r_1^2 + (x_1 - x_2)^2} + \dfrac{r_2}{r_2^2 + (x_3 - x_4)^2}}{\sqrt{\left(\dfrac{r_1}{r_1^2 + (x_1 - x_2)^2} + \dfrac{r_2}{r_2^2 + (x_3 - x_4)^2}\right)^2 + \left(\dfrac{x_1 - x_2}{r_1^2 + (x_1 - x_2)^2} + \dfrac{x_3 - x_4}{r_2^2 + (x_3 - x_4)^2}\right)^2}} \qquad (9)$$

$$\cos\varphi_1 = \frac{i_1^2\, r_1}{e\, i_1} = \frac{r_1}{\sqrt{r_1^2 + (x_1 - x_2)^2}} \qquad (10)$$

$$\cos\varphi_2 = \frac{i_2^2\, r_2}{e\, i_2} = \frac{r_2}{\sqrt{r_2^2 + (x_3 - x_4)^2}} \qquad (11)$$

From these values of $\cos\varphi$ we may obtain the phase angles between the currents and between them and the e. m. fs.

In the preceding, a positive and a negative reactance is assumed in each subcircuit, in order to illustrate the method more clearly. A single reactance might have been employed as representing the algebraic sum of the reactances in each subcircuit, just as the single resistance represents the algebraic sum of the resistances. In Fig. 3 such an expedient has been adopted, in order to simplify operations. In the following equations, therefore, while the reactances are all shown as positive, they may be either positive or negative.

For Fig. 3 we have:

$$(e\,i)^2 = (i_1^2\, r_1 + i_2^2\, r_2 + i_3^2\, r_3 + i_4^2\, r_4)^2 + (i_1^2\, x_1 + i_2^2\, x_2 + i_3^2\, x_3 + i_4^2\, x_4)^2 \qquad (12)$$

But we know from (5) that

$$i_1^2 = \frac{e_1^2}{r_1^2 + x_1^2} \qquad i_2^2 = \frac{e_1^2}{r_2^2 + x_2^2}$$

$$i_3^2 = \frac{e_3^2}{r_3^2 + x_3^2} \qquad i_4^2 = \frac{e_3^2}{r_4^2 + x_4^2}$$

We know from (8) that:

$$e_1^2 = \frac{i^2}{\left(\dfrac{r_1}{r_1^2 + x_1^2} + \dfrac{r_2}{r_2^2 + x_2^2}\right)^2 + \left(\dfrac{x_1}{r_1^2 + x_1^2} + \dfrac{x_2}{r_2^2 + x_2^2}\right)^2} = \frac{i^2}{a^2} \qquad (13)$$

$$e_3^2 = \frac{{}^2i}{\left(\dfrac{r_3}{r_3^2 + x_3^2} + \dfrac{r_4}{r_4^2 + x_4^2}\right)^2 + \left(\dfrac{x_3}{r_3^2 + x_3^2} + \dfrac{x_4}{r_4^2 + x_4^2}\right)^2} = \frac{i^2}{b^2} \qquad (14)$$

In which a and b are used to indicate the quantities in the denominators in order to avoid the repeated writing of them. Substituting these values of e_1^2 and e_3^2 in the equations for currents we have:

$$i_1^2 = \frac{i^2}{(r_1^2 + x_1^2)\, a^2} \qquad (15)$$

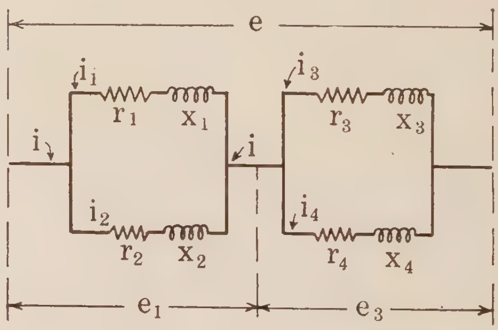

Fig. 3

$$i_2^2 = \frac{i^2}{(r_2^2 + x_2^2)\, a^2} \qquad (16)$$

$$i_3^2 = \frac{i^2}{(r_3^2 + x_3^2)\, b^2} \qquad (17)$$

$$i_4^2 = \frac{i^2}{(r_4^2 + x_4^2)\, b^2} \qquad (18)$$

Putting these values of i_1^2, i_2^2, i_3^2 and i_4^2 in (**12**) and reducing we get:

$$i = \frac{e}{\sqrt{\left(\frac{r_1}{(r_1^2+x_1^2)a^2}+\frac{r_2}{(r_2^2+x_2^2)a^2}+\frac{r_3}{(r_3^2+x_3^2)b^2}+\frac{r_4}{(r_4^2+x_4^2)b^2}\right)^2+\left(\frac{x_1}{(r_1^2+x_1^2)a^2}+\frac{x_2}{(r_2^2+x_2^2)a^2}+\frac{x_3}{(r_3^2+x_3^2)b^2}+\frac{x_4}{(r_4^2+x_4^2)b^2}\right)^2}}$$

$$= \frac{e}{c} \qquad \textbf{(19)}$$

Where c is used to avoid repeating the quantity under the radical.

Substituting this value of i in equations (**13**), (**14**), (**15**), (**16**), (**17**) and (**18**), we get:

$$e_1 = \frac{e}{a\,c} \qquad \textbf{(20)}$$

$$e_3 = \frac{e}{b\,c} \qquad \textbf{(21)}$$

$$i_1 = \frac{e}{a\,c\,\sqrt{r_1^2 + x_1^2}} \qquad \textbf{(22)}$$

$$i_2 = \frac{e}{a\,c\,\sqrt{r_2^2 + x_2^2}} \qquad \textbf{(23)}$$

$$i_3 = \frac{e}{b\,c\,\sqrt{r_3^2 + x_3^2}} \qquad \textbf{(24)}$$

$$i_4 = \frac{e}{b\,c\,\sqrt{r_4^2 + x_4^2}} \qquad \textbf{(25)}$$

The power factors of the circuit as a whole and of the several sub-circuits are found after the manner previously employed. From them can be obtained all the phase angles.

In Fig. 3 let:

$r_1 = 0 \qquad r_2 = \infty \qquad r_3 = 0 \qquad r_4 = r_4$

$x_1 = x_1 \qquad x_2 = \infty \qquad x_3 = -\,x_3 \qquad x_4 = x_4$

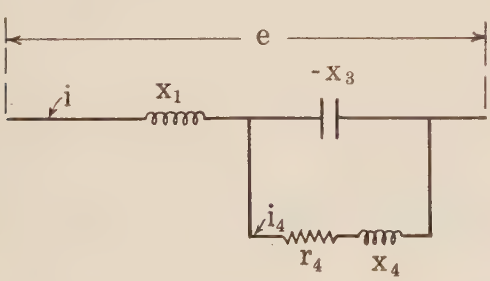

Fig. 4

Then Fig. 3 resolves itself into Fig. 4. And if these values be substituted in equation (**25**) we have:

$$i_4 = \frac{e}{\sqrt{r_4^2+x_4^2+\frac{((x_4-x_3)^2+r_4^2)\,x_1^2}{x_3^2}-\frac{2\,(r_4^2+x_4^2)\,x_1}{x_3}+2\,x_4\,x_1}} \qquad \textbf{(26)}$$

Now let x_3 be numerically equal to x_1. Then equation (**26**) becomes:

$$i_4 = \frac{e}{x_1} \qquad \textbf{(27)}$$

That is, i_4 is constant for all values of r_4 and x_4.

This is Boucherot's beautiful scheme for obtaining constant current from a constant voltage source, and vice versa. Unfortunately, it cannot be fully realized in practise, because we cannot have r_1 and r_3 equal to zero. That is, we cannot obtain a condenser and an inductance with no losses in them. However, the condition of constant current may be closely approximated over a limited range, the closeness of approximation and the extent of the range depending upon how low the losses in the condenser and the inductance, respectively, can be kept.

THE LUMINOUS FOUNTAIN OF PARIS

During a recent exposition in Paris some spectacular performances on the River Seine were carried on by means of a specially built and installed array of luminous fountains. Along each side of the Alexander Bridge a steel pipe 1 ft. in diameter with 9000 small holes was suspended, and a 200-h. p. motor pump delivered water under pressure to these two pipes. The closely spaced water jets formed a parabolic curtain on each side of the bridge. A large number of 2000-cp. floodlights, arranged under the bridge and out of sight, illuminated these two curtains brilliantly. As it was necessary to point all of these floodlights downward, their reflectors had to be watercooled to prevent overheating.

Near the bridge several floating luminous fountains were installed. These were specially designed for the purpose and entirely self-maintained. They consisted of round steel caissons of 23-ft. diameter, containing two motor pumps for the high-pressure water and three rings of floodlamps, throwing beams of light through water-tight glass panels upward upon the rising jets of water. There was room within the caisson for an attendant who changed color filters on the floodlamps. Harmonious color effects were assured by means of telephone interconnections between the fountains and to the shore.

Study of Time Lag of the Needle Gap

BY K. B. McEACHRON*
Member, A. I. E. E.

and

E. J. WADE*
Associate, A. I. E. E.

Synopsis.—*The study of high-voltage, steep-wave-front transients is difficult from the experimental standpoint because of the very short times involved. Due to the improvement which the cathode-ray oscillograph has enjoyed in recent years, a device is now available, by the use of which transients occuring in times as short as one-millionth of a second or less may be photographed. In the paper, the authors used an oscillograph developed by Dufour in France, with which a brief study was made of the time lag of needle gaps and of a needle to a plane.*

A description of the oscillograph is given including a discussion of the method of operation. The photographic film is placed inside the tube so that the electrons impinge directly on the film. The wave is drawn out along a time axis by the combined action of a sweeping motion and a perpendicular oscillating motion imparted to the electron stream by the action of proper electromagnetic fields.

Tests were made with a wave which was nearly perpendicular, reaching its maximum in about one microsecond. Such a wave was obtained by the discharge of a condenser through a suitable circuit. An oscillogram which shows the wave front used is given, and attention is directed to the 20,800 kilocycle oscillation which appears superimposed on the wave front.

The results of tests in which this wave front was applied to gaps are given and it is shown that with any given gap setting and sparking voltage that the time lags vary through wide limits. It is also shown that, for the same voltage, increased gap settings mean increased lag. The per cent overvoltage, required to keep the lag to two microseconds or less, decreases as the gap spacing increases.

* * * * *

The Study of Transients

ONE of the most difficult and perhaps also one of the most fascinating problems which the electrical engineer of today is called upon to study is that of the transient phenomena occurring in electrical circuits. Failure of apparatus, caused by the puncture or flash-over of insulation due to overvoltages, the duration of which may be of the order of a few micro-seconds, has made desirable the use of lightning arresters which limit the voltage to safe values. Since in practise many of the steep front traveling waves are the result of the sudden releasing of a bound electrostatic charge, lightning arrester laboratories have used the discharge of a suitable condenser to simulate the actual line condition. For this purpose, and for the study of the action of insulation and gaps, impulse generators have been built which may be charged to values as high as 2,000,000 volts.

The limitations and some, at least, of the possible sources of error involved in the use of the impulse generator have been recognized by lightning-arrester engineers for some time. Three years ago the authors began to search for means of recording, on a photographic film, transient phenomena the frequency of which might be a million cycles per second or more. As a result of this search of the literature, the device described in this paper was found.

Oscillographs

A satisfactory oscillograph for the delineation of the volt- or current-time characteristic of a short-time transient must satisfy the following conditions:

1. The device must have no appreciable inertia and must be capable of operating at a frequency of at least one million cycles per second.
2. The device must use little energy in its operation, so that its use will not appreciably disturb the original circuit.
3. The device should be capable of registering both voltage and current simultaneously.
4. The apparatus must be so arranged that a single impulse will be sufficient for a satisfactory photographic impression.
5. The oscillograph should be as simple as possbile and have sufficient accuracy so that the results may be used with confidence.

The first point can be satisfied only by some device using the flow of electrons. When thinking of the available devices, one naturally turns to the Braun tube which has been used for many years as an oscillographic device. As originally developed, the Braun tube consisted of a cathode and an anode in an exhausted tube, together with a fluorescent screen. Unidirectional voltage from a static machine causes a flow of electrons from the cathode to the anode, some of which pass through a small hole in the anode and are deflected by magnetic or electrostatic fields produced by the phenomena being studied. The rays then pass on to the fluorescent screen where a graph is traced the coordinates of which are determined by the deflecting fields. If the phenomenon repeats itself, the graph appears as a stationary pattern, and may be recorded photographically using an exposure of several seconds.

The Braun tube has negligible inertia, and very little energy is required to cause the deflection of the cathode beam. Its speed is the speed of the electron which may be varied between quite wide limits especially if using a heated cathode as in the Western Electric tube. The upper limit of velocity is perhaps one-half that of light.

The fourth condition mentioned, that of recording a single impulse, may be satisfied by placing the photographic film inside the tube in such a way that the electron stream impinges directly on the film. This has been done by several investigators with marked success.

The literature of the Braun tube is quite extensive, and but a few of the available references are given at the end of this paper.

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*Both of the Research Section, Lightning Arrester Engineering Department, General Electric Company, Pittsfield, Mass.

Abridgment of paper presented at Regional Meeting of Dist. No. 1, Swampscott, Mass., May 7-9, 1925, and at the Annual Convention of the A. I. E. E., Saratoga Springs, N. Y., June 22-26, 1925. Complete copies to members on request.

To a Frenchman, Alexander Dufour, belongs the credit for adapting the Braun tube to the study of transient phenomena. This development is characterized by means whereby a photographic film is placed inside the vacuum chamber and also an arrangement for drawing out the transient along a time axis so that the highest frequencies may be studied.

The Dufour Oscillograph

A description of this oscillograph which was used in the needle-gap lag tests is given in the following paragraphs.

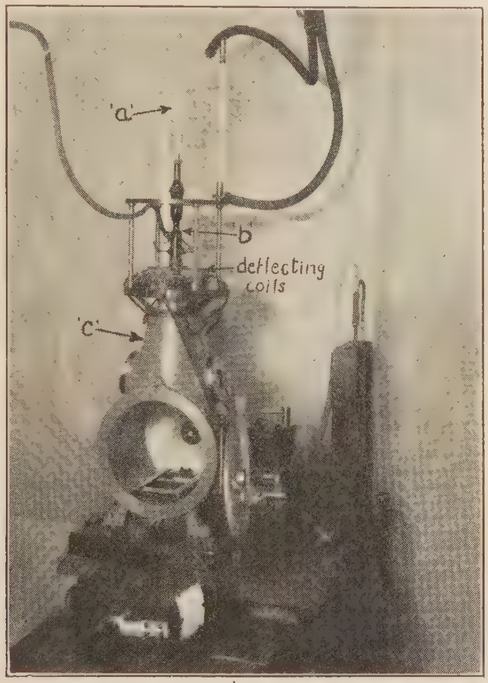

Fig. 1—Dufour Oscillograph

Referring to Fig. 1, the oscillograph consists essentially of glass tubes *a* and *b*, fitted by means of a ground joint into the bronze chamber *c*. The upper glass tube *a* carries the cathode and anode. The tube *b* has one pair of deflecting plates for electrostatic deflection of the electron stream. For magnetic deflection two sets of coils, 1—1 and 2—2 (Fig. 2), perpendicular to each other, are placed external to the tube and located slightly below the deflecting plates. The coils are arranged so that they may be rotated about the axis of the tube, thus allowing adjustment of the angle between the axes of the deflecting fields.

To operate the oscillograph expeditiously, easy means must be provided for changing films quickly. It is also necessary that a fluorescent screen be arranged so that it can be removed when making an exposure. How this is done in the Dufour oscillograph may be seen by referring again to Fig. 1. The drum, which in the illustration appears in the foreground, is provided with a film magazine which allows six films to be taken in succession. When viewing the phenomena, a fluorescent screen is turned up into position covering the opening into the interior of the drum so that the films are not exposed when using the screen. After placing the films in the drum, it is placed inside the bronze chamber and locked in position. The opening is closed by a door having a very carefully constructed joint so that the tube may be made air tight. Three cocks, turning in ground joints placed in the door, serve to operate the mechanism for changing films and moving the fluorescent screen. Two glass windows, one on either side of the bronze chamber, permit of easy view of the fluorescent screen.

Operation of the Oscillograph

For slow speed work a moving drum to take the place of the magazine drum may be used. This drum is driven by means of an external motor and magnetic clutch. A simple calculation shows that such a drum cannot be rotated at a sufficiently high velocity to draw out the oscillations so that they may be studied. To draw out a one million-cycle wave in a manner similar to that used with the ordinary Duddell oscillograph, so that two millimeters are allowed per cycle, would require a film velocity of 2000 meters (6650 feet) per second.

This problem has been solved by Dufour in a very satisfactory manner. Rather than move the film,

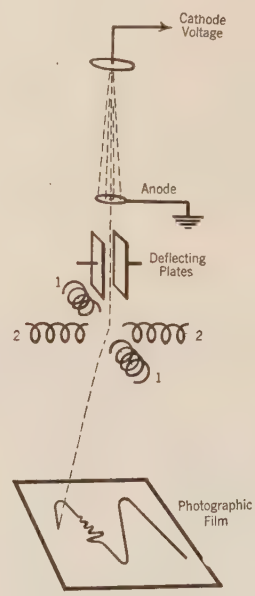

Fig. 2—Diagramatic Representation of Oscillograph Operation

the electron stream is subjected to the action of auxiliary fields which draw out the wave without the limitations of a mechanical system, as shown in Fig. 2. The method by which this is accomplished may be understood by reference to Fig. 3. In I is shown the effect of passing a transient current through coils 1—1. With the proper circuit arrangements the beam is held off the film at the top until ready for the photograph to be taken, when a transient takes place which sweeps the beam across the film holding it off the film at the

bottom. This transient current will be referred to as the sweeping current.

A source of high frequency (a vacuum tube oscillator) is connected to coils 2—2, which are mechanically spaced 90 deg. from coils 1—1. With coils 2—2 energized, the oscillator traces a straight line on the film, the amplitude usually being adjusted to utilize the entire width of the film. When coils 1—1 and 2—2 are operated together the oscillator waves are drawn out as seen in III. If the oscillator frequency is 50,000 cycles and the effective width of the film 100 mm. (3.9 in.), then the average distance corresponding to one micro-second would be 10 mm. (0.39 in.). This means that if a million-cycle wave was impressed on the deflecting plates so that the beam was deflected thereby in the same direction as by the sweeping current, it

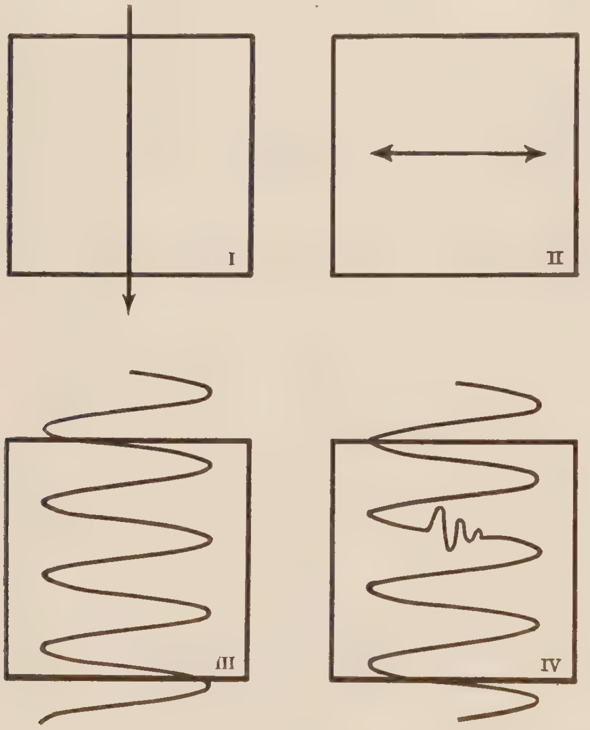

FIG. 3—METHOD OF REGISTERING TRANSIENT PHENOMENA
I. Sweeping III. Sweeping and Oscillator
II. Oscillator IV. Transient superimposed on III

would be drawn out sufficiently so that the wave form could be determined and IV shows the effect of the combination of the three fields. The oscillator wave is the zero line for the transient being studied and it is a time axis whose unit of measure is varying according to the sine law. The speed of sweeping is always a compromise between drawing out the oscillator wave and the difficulty of getting the unknown phenomena timed so as to appear on the film. With much slower speed phenomena, the sweeping field may be placed 90 deg. from that of the unknown transient, so that the time axis becomes a straight line across the film. This axis may be conveniently calibrated by superimposing a known high frequency using the oscillator coils.

Thus it is possible to get volt-time or ampere-time curves with a time axis which can be calibrated with considerable accuracy. Volt-ampere characteristics may be taken by applying to the cathode stream, fields proportional to the voltage and current and spaced 90 deg. apart.

THE CATHODE STREAM

The best registration on the film is obtained when conditions are such that a fine pencil of rays strikes the film only when required. Not only is it desirable to hold the rays off from the film before and after the transient, but the operation of the tube is much improved if the cathode voltage is applied for just sufficient time to allow the proper registration of the unknown transient.

The necessary cathode potential may be obtained by the use of either a high-voltage direct current, or a few degrees of the crest of an alternating potential The latter method may only be used with phenomena which are fast compared to the change of potential. during its registration. This method was mentioned by Dufour as being particularly adapted to the study of very short time transients, and as this method is very convenient it was adopted for use in this study of gap characteristics.

TIMING THE TRANSIENT

The spot made on the photographic film by the electron stream may travel as fast as 80 km. (50 mi.) a second across the film; and since it is not feasible to get a developed registration length of more than 10 or 12 meters (32.8 to 39.2 ft.) on the film, the transient must be initiated during the very short interval of time in which the spot is sweeping across the film.

A rotary switching device has been built which makes the necessary contacts so that voltage is applied to the cathode, the sweeping started and the unknown phenomenon so timed as to appear on the film. The oscillator is connected before voltage is applied to the cathode, and remains connected until after the exposure has been made. The arrangements are such that only the pushing of a button is required to set in operation a mechanism which makes all connections automatically.

TIME LAG OF NEEDLE GAPS

It is known that a needle gap shows considerable lag when subjected to steep wave front impulses. The brief study which is presented herewith measures definitely the lags encountered under the given conditions. The results are not complete, but do give for the first time, as far as the authors are aware, a direct measurement of lags as short as a few micro-seconds. The methods used here are being applied to the study of the problems encountered in lightning arrester practise and will yield results of great importance.

The time lag of a gap may be taken as the time elapsing until breakdown occurs during which the applied potential exceeds the low frequency spark potential. For a voltage only slightly in excess of the

low frequency spark potential the time lag may be long, while with steep wave fronts of high voltage it will be extremely short. The lag with any given gap is determined not only by the voltage at the time of spark-over, but also by the shape of the wave front used.

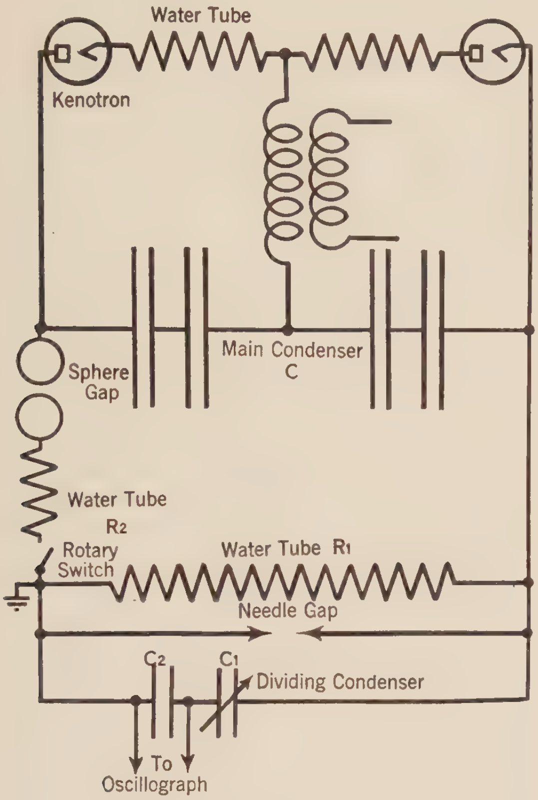

Fig. 4—Connection Diagram

The purpose of these tests is to find the effect of successive increments of overvoltage on the time lag. To avoid the complication of a sloping wave front, it was thought best to use as nearly rectangular a wave as could be obtained. It is impossible to produce a perfect rectangular wave but if the time required for the voltage to reach a constant value is small in comparison with the time taken by the gap under test to spark over, the error will be negligible.

Test Arrangements

An impulse generator, which was built for use in connection with the testing of lightning arresters, was used as a source of voltage. This generator consists of two hundred glass plates with tinfoil coatings divided into four groups connected in series, each group consisting of 50 plates in parallel, giving a capacity of 0.13 microfarads. A connection diagram is given in Fig. 4 and shows the limiting sphere-gap which determines the voltage at which discharge will take place. The water tube resistance, R_1, allows the sphere-gap to charge up properly, while R_2 is used to control the wave front as will be shown later. The dividing condensers, C_1 and C_2, were used for reducing the voltage to the proper value for the deflecting plates on the oscillograph.

The oil-immersed dividing condensers are shown in Fig. 5, together with the needle gap being tested. The capacity of C_1 at the setting used on the tests was about 20 micro-microfarads. Variable stray capacities to ground and inductive effects between the condenser and the oscillograph were eliminated by using a ground shield around the dividing condenser.

Voltage calibrations were obtained from capacity measurements, and more directly by taking oscillograms when holding a known 60-cycle voltage on the dividing condensers.

Wave Form

Fundamentally, the circuit shown in Fig. 4 represents the discharge of one capacity into another with small series inductance and considerable series resistance. The circuit is of course complicated by the use of series gaps, wires leading to oscillograph, etc. With such a circuit, the series resistance R_2 will increase the time required to charge the capacity of the dividing condenser and connections.

The effect of changing R_2 may be seen by referring to Fig. 6, which shows the wave fronts with three different values of resistance. The method of registration used is the same as that described in connection with Fig. 3 and consists in applying an upward sweeping motion, combined with the horizontal motion of the oscillator. Superimposed is the discharge of the condenser which is initiated by the action of the rotating switch.

On the oscillograms given in Fig. 6 will be found two sets of oscillations, the first being damped out rather quickly. This oscillation, which has a frequency of approximately 20,000 kilocycles, occurs when the rotating switch sparks and is followed by another when the limiting gap sparks. There is a certain variable time interval between the sparking of these two gaps.

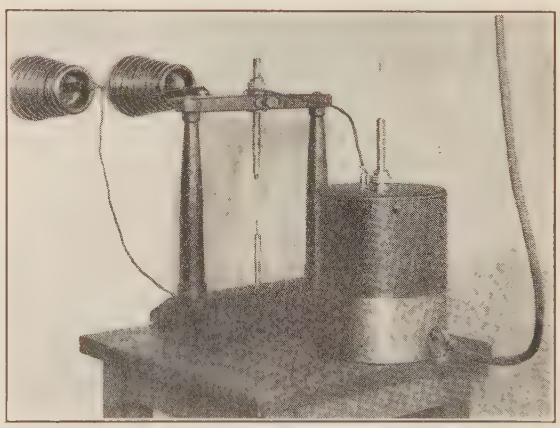

Fig. 5—Dividing Condensers and Test Needle-Gap

In making these tests the aim was to obtain a steep wave front but at the same time to prevent the voltage from over shooting. Film 300 (Fig. 6) shows the main

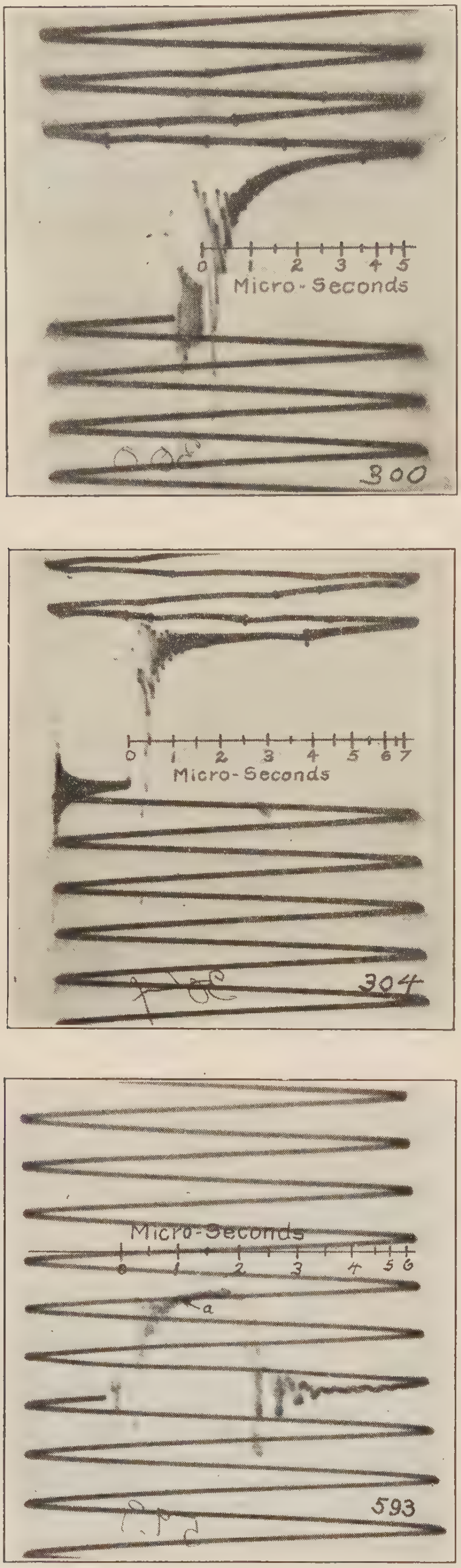

Fig. 6—Oscillograms Showing the Wave Front Used on Needle Gap Tests

Film 300—Oscillator frequency 42.6 kc showing wave form with 1100 ohms series resistance. Voltage reaches constant value in 2.5 micro-seconds.

Film 304—Oscillator frequency 42.6 kc. Wave form with 570 ohms series resistance. Voltage reaches constant value in 0.4 microseconds.

Film 593—Oscillator frequency 50 kc. Wave form with 700 ohms series resistance. Voltage reaches constant value in 1.0 microseconds. Needle gap sparks after 0.83 microsecond. Gap setting 65mm. voltage 75 kv.

transient rising to its maximum value in about 25. micro-seconds. Superimposed on this wave front are oscillations which are made up of a combination of several frequencies. Film 300, which was taken with 1100 ohms in series, shows that none of the oscillations has a voltage exceeding the maximum value of the main transient.

The series resistance was reduced to 570 ohms and film 304 taken. This film shows that the main transient rises to its maximum in about 0.4 micro-second. This resistance is too small however, as some of the crest values of the superimposed oscillation exceed the final voltage. A value of 700 ohms was chosen as being the best compromise between the steepness of wave front and the condition of overshooting. Film 593 was taken, using this series resistance, and it was found that a time of one micro-second was required for the voltage of the main transient to reach its full value (marked *a* on the film). This film is interesting as it shows the sparking of a needle-gap 0.8 micro-second after full voltage had been applied.

Results of Tests

The time lags under most test conditions used exceeded two micro-seconds, which made the use of the oscillator undesirable except for timing purposes; therefore, nearly all results were taken with the sweeping only, as this allowed several exposures on one film. With six films and five tests per film, it was possible to get 30 tests before releasing the vacuum and changing the magazine drum. The use of the sweeping also gives a uniform time scale for the measurement of the lag.

The results of nine representative tests are given in Figs. 7A and B. As this type of oscillogram is probably new to most of the readers of this paper a brief explanation is given. The different tests are numbered in the order in which they were made. In the first test, for instance, which is at the bottom of the film, (No. 543), the cathode spot comes on the film from the left, being swept across the film at a uniform rate corresponding to 4.5 micro-seconds per mm. About 190 micro-seconds later the voltage is applied by the operation of the rotating switch. The cathode beam is deflected upward and traces a horizontal line, parallel with the zero axis, until after 140 micro-seconds the needle-gap under test breaks down and the cathode spot falls to zero and so continues, passing off the film at the right. Although the wave front in this film appears perpendicular, it is really as shown in Fig. 6, film 593.

Four needle-gap breakdowns are given in film 558, Fig. 7B, the voltage being 5 kv. with a needle gap spacing of 60 mm. This film shows a 50-kilocycle timing wave which fixes the time calibration. Fig. 7A film 543 shows the result of tests on a 15-mm. needle-gap with 22 kv. applied. These oscillograms show very nicely the steepness of the wave front compared with the time lags; and also how well the cathode ray oscillograph is adapted to the study of short time phenomena.

Results were obtained from a series of oscillograms for three different voltages and with different needle-gap spacings. Tests were also made with a needle to a plane and between needles having different degrees of sharpness. Some of the results are given in Table I.

An analysis of the results brings out certain relations which are briefly discussed.

For each voltage used, the gap setting, corresponding to infinite lag, will be slightly above the 60-cycle setting for that voltage. The per cent overvoltage above the 60-cycle spark potential necessary to obtain lags of one micro-second or less was found to decrease with increased spacing.

With spacings of 10, 40 and 65 millimeters the per cent overvoltages are 75, 40 and 29 respectively. It is, of course, to be expected that the greater the per cent of overvoltage the shorter the time lag. The results show that this is true, in general, although wide variations in time lag occur with every setting and at all voltages.

An examination of the results discloses the existence of time-lag zones, which indicates that breakdown is more likely to occur within these zones than outside. The existence of these zones is doubtful in some cases, while in others it seems well defined, as for instance at 75 kv. with a 95-mm. spacing (Table I).

In general, the tests show that dull needles give shorter time lags than sharp needles, although more tests should be made to be certain of the relationship.

Comparing the point-plane tests (Point negative), with the needle points having the same spacing the data show that the lags are of the same order of magnitude although the maximum lag with the point-plane is considerably greater than the corresponding value for the points. Tests made with the point positive show that the lag is less than two micro-seconds while with

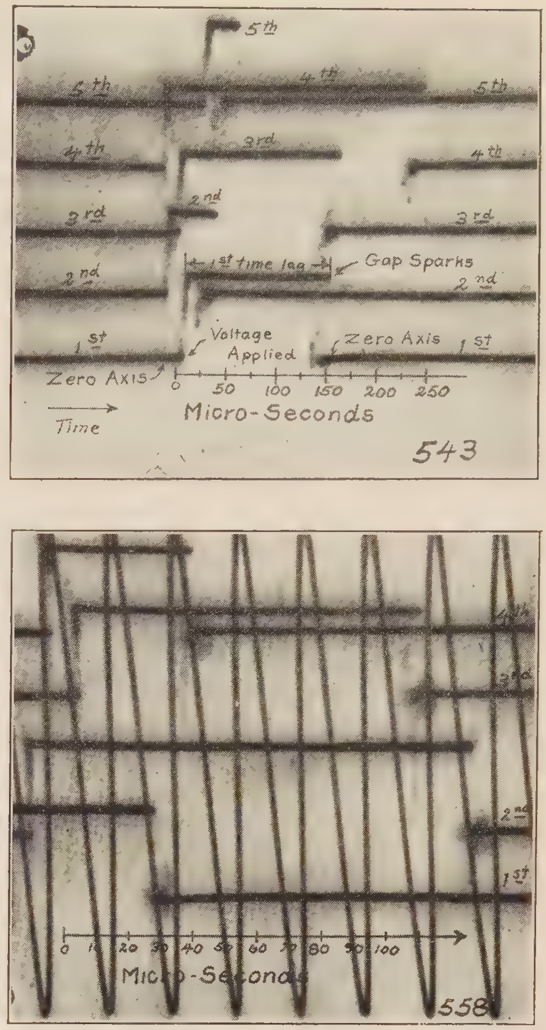

Fig. 7—Oscillograms Showing the Time Lag of Needle Gap

Film 543—Five tests on needle gap at 15 mm. 22 kv.

Film 558—Four tests on needle gap at 60 mm. spacing 58 kv. 50 K C Timing wave.

TABLE I—TEST DATA
LAGS GIVEN IN SAME ORDER AS TESTS WERE MADE
VOLTAGE 75,000

Spacing and Gap	Atmospheric Conditions	Time Calibration Micro-seconds Per mm.	Time Lags in Micro-seconds	Max. Min. Av.	Per Cent Sparking 1st Range	2nd Range	3rd Range	4th Range
95 mm. Needle Gap 70 per cent sparking at this setting	Relative humidity 14 per cent Bar. 29.1 in. Temp. 22 deg. C.	8.5	120– 21– 88– 42– 25 491–406– 34–340–466 339–440–400–460–400	Max. 491 Min. 21 Av. 260	40	0	14	46
80 mm. Needle Gap	Relative humidity 14 per cent Bar. 29.1 in. Temp. 22 deg. C.	5	35– 45–280–240–250 35– 40– 30–235– 30 35– 30– 35– 35–335 235– 40– 15–210–230 300–200–250– 45– 30 35– 35– 40– 35–210	Max. 335 Min. 15 Av. 120	58	0	28	14
72 mm. Needle Gap	Relative humidity 26 per cent Bar. 28.8 in. Temp. 19 deg. C.	2.4	38– 38– 43– 48– 26 43– 29– 38– 21– 48 29– 45– 29– 29– 29 29– 2– 17– 55– 60 31– 53– 41– 31– 31	Max. 60 Min. 2 Av. 35	4	48	28	20

the point negative with the same spacing and voltage an average lag of 62 micro-seconds was obtained. When the point was negative with a spacing of 13 mm. sparking occurred with approximately 50 per cent of the voltage applications. With the point positive a similar condition was obtained with a spacing of 19 mm. These results give some conception of the effect of polarity on the lag of a point-plane gap.

Conclusions

An oscillograph is now available, as represented by that made by Dufour, by the use of which single transients may be photographed, without being limited by the inertia of a mechanical system. By its use, wave forms have been photographed having measurable oscillations up to 20,000 kilocycles. The authors have worked with an oscillator frequency of 250 kilocycles which allows the registration of a frequency of 100,000 kilocycles. As the frequency increases, the problem of the characteristics of the circuit used become increasingly important and great difficulty is experienced in keeping the oscillograph circuits free from disturbances emanating from the main impulse circuit. The cathode-ray oscillograph, as used here, becomes a tool of the greatest value in the study of transient phenomena.

The lag tests, with constant voltage on the needle gaps, show that the lags vary between wide limits, the average lag increasing with increased gap settings. The limits could probably be narrowed considerably by the use of careful control of air and electrode conditions. The per cent overvoltage, required to keep the lag to two micro-seconds or less, decreases as the gap spacing increases. The lag is shown to depend on the condition of the needle, the dull needle tending to have the shorter lags.

The authors are continuing the use of the oscillograph, intending to apply it to the study of transients on transmission lines due to lightning and other causes. The breakdown of insulation and the operation of lightning arresters is also being investigated. Acknowledgment is gladly given to the work of Alexander Dufour, who constructed the oscillograph used by the authors in the work described in the paper.

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Discussion at Pacific Coast Convention

220-KV. TRANSMISSION TRANSIENTS AND FLASHOVERS[1]

(Wood)

Seattle, Wash., September 15, 1925.

Percy H. Thomas: This paper appears to clear away definitely the persistent suspicions that there is some source of mysterious overpotential inherent in 220 kv. or in very long lines, that does not appear on the surface—something involving an unrecognized principle and jeopardizing reliability of service.

The subject of surges and high-voltage breakdowns has long been a *bête noir* for transmission operation. When power transmission first became of importance, one of the first serious sources of shut-down other than the ever-present lightning was the frequent short circuit of transformers in high-tension service. While this proved to be due partly to moisture and inadequate insulation, it was, nevertheless, necessary that the now well-known but then almost unknown effect of the steep-wave-front surge on windings be studied out[2] and this led to radical change in the method of insulating high-tension windings. While the theory of the propagation of surges or waves in transmission lines was academically known, nobody knew what the real effect in an actual line practically was and this led to a certain feeling of uncertainty as to what might be expected with plant extensions. This led to a series of investigations in 1902 in the middle west on a number of high-tension plants, similar in object to those reported by Mr. Wood and leading to a somewhat similar conclusion.[3] In the old investigation, the voltages were lower and the apparatus cruder but the interest was much the same.

At still a later period, with the advent of larger systems and higher voltages, still another experimental study was made, this time based largely upon the oscillographs covering the action of switching and surges in the system of the Pacific Gas & Electric Company[4] and still again with the result of disproving the existence of any new or unexpected phenomena.

Mr. Wood's work goes over the research again, taking up all possible sources of excessive surges and using perfected apparatus. This makes clear the conclusion that the explanation of mysterious surges even on 220-kv. lines must be sought among the well recognized laws of electric phenomena.

Considering, now, the detail of the paper, it may be pointed out that the results of the klydonograph appear to agree with the old fundamental rules of wave motion, e. g.: (a) When a potential is abruptly applied to a transmission line, a wave equal in crest to the applied potential passes along the line until it reaches a reflecting point when it is reflected back toward the start, reaching *double potential* at the *reflecting point*, neglecting losses. (b) When a small-capacity branch line leads from such a reflecting point, the wave starts off in the branch line at the maximum potential reached at the reflecting point and is subject to reflection at the end of the branch line with another doubling of the potential. (c) Whenever a condenser is charged

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2. See paper Percy H. Thomas, Trans. A. I. E. E., "Static Strains in High Tension Circuits and the Protection of Apparatus," Vol. XIX, 1902, p. 213.
3. See paper Percy H. Thomas. *An Experimental Study of the Rise of Potential on Commercial Transmission Lines Due to Static Disturbances Caused by Switching, Grounding, etc.*, Trans. A. I. E. E. ,Vol. 1905, p. 317.
4. Guiseppe Faccioli, *Electric Line Oscillations*, Trans. A. I. E. E. Vol. XXX, Part III, p. 1803.

through reactance (neglecting resistance) the potential will rise to double the charging potential and only gradually settle down to equilibrium after a series of oscillations.

As Mr. Wood properly says, in considering surges in a line, the effect of distance of travel is only to weaken the surge. Other things being equal the effect of a switching operation is greatest nearby.

It is particularly gratifying to find that no abnormal *sustained* high-frequency potentials exist in the line, as these might be exceedingly troublesome.

F. W. Peek, Jr.: Mr. Wood's findings, which are quite in accord with theory, show no mysterious high voltages at sustained high frequency causing arcs of indeterminate distance. The expected highly damped switching surges occur but never of sufficient voltage to cause trouble. The cause of many arc-overs is dirt. In the tests made most of the dirt trouble was a purely mechanical one due to birds and as easily understandable as the effect of a fuse wire dropped over an insulator string. This investigation shows conclusively that there need be little fear from transient voltages originating in a grounded-neutral system.

Thus, in the part of the country where the lines of the Southern California Edison Company are located the chief cause of insulator arc-over is a weakening of the insulators by dirt or other mechanical means.

Other important points brought out are that high-voltage switching may be done without fear, and that with quick-acting relays insulator arc-overs may be cleared without interruption of service. Of course, in addition to quick-acting relays, it is important to have grading shields or rings on the insulator to direct the arc away from the string while the relays are operating.

While dirt is the principal cause of arc-over in certain parts of the country, in other parts its effect may be practically negligible and lightning may be a very serious factor.

To illustrate how well Mr. Wood's conclusions are in agreement with our laboratory investigation I would draw your attention to a recent discussion of mine[5] at the Annual Convention which shows that our conclusions are very similar to Mr. Wood's.

C. L. Fortescue: Klydonograph is derived from two Greek words which mean wave and record. It is a device for making a record of surges. The klydonograph is a very simple instrument which consists merely of an electrode which is connected to the line through a potentiometer device, and measures a voltage proportionate to the tension of the line. This electrode passes over a sensitized plate or film in contact with the insulated surface of a grounded plate. Now the oscillation passing over the line makes a record on this sensitized plate which, after development, shows a figure possessed of certain peculiarities. A figure for a positive wave in any direction is different from the figure for a negative wave, so that it is possible to tell what the polarity of the wave is. One can tell whether it is an oscillating wave and, with certain arrangements, know not only the character of the wave, but also the steepness of the wave fronts and the direction in which the wave is traveling. So, with this device, it is possible to obtain very complete information about surges.

The method of determining the amplitude of the wave consists in measuring the diameter of the figure. The diameter is very closely proportional to the actual amplitude of the wave within the range in which this measurement is useful. In other words, for the higher voltages where the surges are of some concern, the calibration is very close, within 15 per cent.

The first klydonograph consisted merely of an ordinary sensitized photographic plate rotated under the electrode and the plate had dials which would register time on the record. The complete rotation occupied one day. This, of course, was not very convenient inasmuch as the plates had to be changed every day. The present klydonograph is a much more suitable instrument. It consists of the same arrangement except that it has a roll film which goes over an insulated grounded cylinder. The roll needs to be changed only once a week and provision can be made for longer or shorter periods as desired.

Now, so far as possible, we are giving klydonograph service to those who have problems requiring investigation. We have about twenty of these seven-day instruments in operation. We have two experts whose work is devoted solely to looking after the instruments and giving this service. We have investigated quite a large number of systems in the east.

Of course, in carrying out this work we aim to do our field work as much as possible during the summer months when we have lightning, etc., so that we have been able to make only a preliminary analysis of the results. The preliminary analysis shows that in no case were there any signs of high frequency and, in fact the highest frequency we obtained was something less than 30,000 cycles per second. The duration of these surges is very brief. They don't travel very far. They very quickly become damped so the bogey of sustained high frequency does not exist. We haven't found it anywhere. Our experimental work has extended particularly over such portions of the United States in which lightning is very frequent and severe.

Lightning has proved to be the most prolific source of high voltages, but even lightning has caused nothing we need fear. The highest voltage hasn't gone beyond the possibility of insulation.

We expect to carry on this service to the best of our ability, but of course, we are limited as to men and also as to number of instruments. On a large system it is pretty hard to do with less than a dozen instruments; to carry out investigations properly, one should have more.

We expect to do some theoretical work in the winter months, analyzing results of the investigations of the previous months; and we probably shall have to do some work on cable systems during the winter. Cable systems have been very free from surges and that, of course, from theory is what we expect. We wouldn't expect to have the surges in cables due to effects outside, and surges from cables connected to outside lines don't amount to anything at all. I don't think that the trouble with cables can be attributed to outside sources. The troubles with cables are inherently inside the cables themselves; surges may come about due to the trouble in the cables, possibly.

I may state that grounded-neutral systems have been very free from surges due to short circuits and other abnormal operations.

J. H. Cox: Mr. Wood's instructive paper leaves little to be said to lay the ghost of alarming abnormal conditions on the 220-kv. lines of the Southern California Edison Company. As pointed out, the tests were sufficiently extensive to be truly representative of conditions on those lines. Since Mr. Wood's paper tells the whole story so far as his system is concerned, it seems appropriate to present information gathered more recently with the klydonograph on other lines.

During the year 1925 surge investigations have been made on quite a number and variety of systems, both open-wire and cable. The causes of abnormal voltages on transmission lines may be classed under three headings, switching, short circuits and grounds, and lightning.

Switching. For the most part the experience with surges resulting from operating activity has been much the same as that on the Southern California lines. Switching surges in general are less than two times normal in terms of crest voltage to ground. Only two types of operations caused higher surges. One of these was the opening of an idle but energized line on a 15-mi. free-neutral line and caused surges as high as 4.3 times normal. The other was synchronizing with a high-voltage switch at the end of a 150-mi. free-neutral line. These surges reached a maximum of 4.6 times normal.

5. A. I. E. E. Journal, October 1925, p. 1151.

Short Circuits and Grounds. Experience with short circuits and grounds on other grounded-neutral systems has agreed with that on the Southern California Edison lines. No major surges on such lines have resulted from short circuits and grounds either accidentally and intentionally produced. Short circuits and grounds on free-neutral systems have, in general, produced high-voltage oscillations reaching a maximum of 4.5 times normal. These voltages were recorded on the two ungrounded phases in the case of a single-phase ground.

Lightning. As would be expected, lightning has thus far proven to be the best generator of high-voltage surges though in the California Edison System high voltages due to this cause were absent. No differentiation is made by this source between types of systems but it varies widely with locality. In one case a voltage of 1000 kv. to ground was recorded. Many other surges caused by lightning were recorded, ranging from 400 kv. to 700 kv. Some of these were oscillating and others unidirectional. The unidirectional surges were positive in polarity. The oscillating surges were usually recorded at times when an interruption was caused by the stroke.

R. W. Sorensen: During the past twelve years I have been much interested in these line flashovers. Some of our first theories as to the cause included mechanical means, such as spider webs, dirt, soiled insulators, etc. As a basis of the spider-web hypothesis there were found many big spider webs attached to the lines and it was supposed that these webs might become wet and cause some of the flashovers. The possibility of these flashovers being caused by birds was also considered. But, at that time, there was never sufficient conviction to warrant the expense of erecting devices to keep the birds away from the towers as has been done recently.

It is my endeavor in this discussion to encourage the idea of trying to solve our difficulties by doing simple things first, although it seems to be human nature to first apply complicated methods and later simple methods to problem solutions. One of the objects of engineering education should be to teach us, as engineers, to avoid a complicated method of attacking problems.

It must be borne in mind that, although it has not been mentioned in Mr. Wood's paper, he is dealing with a line to which are connected transformers with delta connections so that on this line there is no probability of getting effects such as arcing grounds might produce on Y-Y connections if these connections are not properly supplemented with tertiary windings connected in delta.

G. R. F. Nuttall: Perhaps it would not be out of place to mention the 220-kv. tie line between the Great Western Power Company and the San Joaquin Light & Power Company.

The design and tests on the standard towers have just been completed and Mr. J. A. Koontz, of the Great Western Power Company has taken particular care to shield all points on the towers so that no corona will form near the wires. In order to reduce eccentricity in the joints, it is better to place the bracing in the cage of the towers alternately inside and outside. This inside bracing ordinarily offers quite a sharp edge which is a point where corona might form. Therefore we have bolted a small angle to the outside brace which exposes its flat side to the wire.

Mr. Wood mentioned that they used a dynamometer in stringing their cable, I wonder if we could have information as to the type used, as the spring type is unreliable at the higher tensions.

I should like to present for discussion the question of insulation, not of the line itself but at the ends of the line. Mr. Wood's paper has given us useful information on transient voltages and 220-kv. operation and I wonder what the manufacturers' views are as to the rating of their bushings for oil switches and transformers.

In the case of the Pacific Gas & Electric Company and the Southern California Edison Company I think I am right in saying that the A. I. E. E. ruling (Sept. 1922), has not been upheld. The switch bushing ought to be tested for 2¼ times the line-to-line potential which equals 495 kv. for 220 kv. operation, and the transformers (three single-phase, auto-transformers with grounded neutral) at an induced voltage of twice line-to-line potential plus 1000 which equals 481 kv. for 240 kv. at the sending end.

L. N. Robinson: In connection with Mr. Wood's paper, the most effective cure for the flashovers seems to be the bird guards. I wish Mr. Wood would give us a description of them.

D. I. Cone: I wish to comment on a by-product result of Mr. Wood's paper. The table on the seventh page and the oscillograms, tells of the investigation of the normal residual currents of the system, which were found to be without features that would aid in the explanation of transients. This record, if supplemented by data regarding the sizes of transformers, their characteristics and connections, will be of considerable value to the Joint Committee of the National Electric Light Association and the Bell Telephone System, which is studying the distribution of such residual currents in systems of this kind. A special project committee is doing work with a view to enabling us to predict these residuals and their resulting inductive effects upon neighboring lines.

Roy Wilkins: In the discussion on Mr. Wood's paper the question is brought up regarding the insulation on the oil switches and bushings and transformers used on the 220-kv. line. The transformers and switches themselves are tested for 2.73 times the normal voltages to ground; the bushings at 2.25 times line voltage. There is before the Institute's Standards Committee at the present time the proposition to change the requirements for the potential tests on grounded transformer equipment to some such value at 2.73 times line voltage.

H. Richter (communicated after adjournment): The paper states that, on the small overhead networks, the transformers are of the type having a network protector in the same case. This form of network protection has been abandoned on the two systems where it originated, because of faulty operation and lack of real protection. Experience shows that these devices are excellent transformer protectors but cannot be relied upon for network,—that is, service protection. I am rather inclined to ascribe the excellent record of 0.7 per cent transformer burn outs mentioned on the seventh page to the lightning protection offered by the common system neutral, as emphasized on the fifth page. As these protectors are so designed that they do not protect against trouble in the primary or secondary lines, their cost of about $3 per transformer-kv-a. makes a rather high insurance rate against transformer trouble. The substitution of carbon circuit breakers tripped by reverse-power relays in the underground area of Minneapolis is in line with the latest methods of network protection where real reliability of service is demanded.

In general it may be said that the loop method of primary feed is particularly applicable to bulk loads of 300 kv-a. up and fed at the higher primary voltages of 11,000 volts and above. This is because of the high cost of spare capacity in feeders and substation apparatus, high rupture capacity, loop-sectionalizing switches, and pilot-wire control. For underground areas where transformer banks, serving miscellaneous distribution loads, range from 75 to 300 kv-a. each and are spaced on the average 500 ft. apart (but may be up to a maximum of about 1000 ft. apart) there is being installed in six large cities and planned for many others, a very simple system of a-c. distribution. This is the secondary-network system with automatic network protection that was described by A. H. Kehoe[6] and by W. R. Bullard,[7] and that has been in successful operation in New York City for almost three and a half years.

6. Underground Alternating-Current Network, by A. H. Kehoe, A. I. E. E. TRANSACTIONS, 1924, p. 844.

7. A Study of Underground Distribution Systems, by W. R. Bullard, A. I. E. E. TRANSACTIONS, 1924, p. 856.

In this network system the feeders are radial, no primary protective or sectionalizing devices being necessary. The secondary mains are spliced together to form a solid mesh which requires no junction boxes and a compact triple-pole network unit, inserted in the transformer-secondary connections to the network, protects for every type of fault that might interfere with continuity of service except failure of the prime source of power. Advantage is taken of the elimination of primary switches, cut-outs and disconnecting potheads, to employ higher primary voltages such as 13,200 volts. Thus may be saved the cost of either station step-down transformers and lower voltage switches, or even of the entire substation. By limiting the feeder capacity to 150 amperes, each feeder can carry about 3000 kv-a. and be confined to either a small or a large area depending on the load density.

The system of multiple street lighting introduced in Minneapolis is undoubtedly a step ahead both from an operating and economic point of view. However, some electric service companies object to pilot wires for control and others to mercury switches. One manufacturing company has developed a system of control by a form of carrier current over the primary feeders. This dispenses with both of these features and also the reenergizing contactors. The switching units are sturdy, comparatively simple, will not be expensive and are small enough to mount in the vase of an ornamental post. They can also be used in conjunction with a primary switch, for controlling pole-mounting constant-current transformers feeding series lamps. The sender at the station is likewise simple and substantial. Further, there are practically no losses in the switching units.

The system has had a successful trial equivalent to a year's service. It is anticipated that this method of control, together with multiple street lighting, will be the standard street-lighting system of the future.

R. J. C. Wood: There was a question asked about possible slipping of aluminum on steel with changes of temperature. I have given that matter quite a little thought and have come to the conclusion that there is no longitudinal motion between the two metals. Imagine a piece of cable, steel inside and aluminum outside; somewhere it has two ends clamped together, so that the two ends cannot move with respect to each other. If you make it sufficiently hot the aluminum expands away from the steel, but in an actual line, the tension of the cable is sufficient to stretch the steel so that the aluminum does not become loose. In actual construction, I doubt if you will find separation of the aluminum from steel. They will act together as a unit with this exception: with changes of temperature the stress passes from one to the other. The hotter the metal, the greater the stress in the steel; the colder the metal, the more stress in the aluminum.

In closing my paper: the design of the bird guards has been a matter of trial and error. We equipped a portion of the line with what is known as Mr. Barre's bird pans. The bird pans consist of a horizontal tray of metal lying on the lower member of the top crossarm, the idea being that it would form an efficient mechanical shield between the bird and the conductor. Apparently they have worked quite successfully, the only objection being that they are rather expensive, and unless they are very well anchored to the members of the tower, the ordinary vibration sets them imitating big drums, so that there has been some complaint from real estate agents trying to sell property in the immediate neighborhood.

There is another kind of bird guard which is simply an exaggerated saw-toothed, galvanized iron, the points being perhaps 1½ or 2 in. apart and with a height of some 6 in. so that it is a very acute point which is not comfortable to the bird. These were fastened along the members of the tower for a distance of approximately 5 ft. on each side of the center conductor. This line, by the way, is of horizontal construction, and similar pieces of metal were fastened to the sloping portion of the crossarm in the outer positions.

When we first put up these bird guards as mentioned in the paper, we didn't know what a clever fellow the bird was, and we put up one kind of a guard to protect the place we thought he was going to roost upon, but, driven out of there, he took the next best thing. He even goes so far as to climb into a little piece of 6-in. channel which is underneath the main crossarm, a piece only about a foot long, which is a part of the structure from which the center string of insulators is hung. When prevented from getting on the main body of the crossarm, he flew underneath and got into this little cage place, so we have had to protect that too.

Regarding the residual currents and the situation of the transformers and auto-transformers, the information Mr. Cone asked for can be given him, but it really will not be of very much use since it refers to a line which is not transposed. We have been trying ever since the line was built to find time to transpose the conductors, but we have never had time to take the line out of service and do this work. As soon as the third line is in, we expect to be able to take out the other two lines, one at a time, and transpose them. This will balance them, statically, against ground, and will reduce to a considerable degree that residual current.

THE LINE OF MAXIMUM ECONOMY[1]

(Kirsten and Loew)

Seattle, Wash., September 16, 1925.

C. E. Carey: It seems to me that the authors have laid down a premise which at this time I would like to question, whether or not it is the fundamental premise of this paper.

I question the statement which reads: "Therefore, the basic assumption is made that for maximum economy all lines should be operated at an average voltage slightly below the critical disruptive value of the conductor used. To make the assumption more specific, 90 per cent of the critical disruptive voltage will be assumed as the correct value of the average line voltage in all cases."

When we consider an economic transmission line, we balance the annual cost against the losses, or, in other words, we strive to develop a line which gives the lowest annual operating expense per year, including interest, depreciation and losses. Why is there no voltage above the critical corona voltage which is the economical voltage? The losses due to corona enter into these annual charges as a fixed charge and therefore have a proper place in arriving at an economical voltage.

I would like to ask the two gentlemen if they have established, as a fact, that the economic line voltage is always under the critical corona voltage.

F. G. Baum: I should say the authors started out with the wrong assumption; that is, that the voltage is fixed. If you follow the theory given, in every line you would have a voltage depending on the length of the line. Can you imagine the maze of voltages we would have in the country if such a principle were followed? You can fix the voltages and then, by taking aluminum or copper lines, get exactly the same economic results. That is shown by the City of San Francisco, which put in a line recently of 150,000 volts for 150 mi. They used that old factor of 1000 volts per mile. There has been no good reason for that rule. Someone said it one time, and it was untrue then, and has been untrue ever since.

They applied Kelvin's law to the design of this line, and the work done in the paper I think is very commendable, but Dr. Kelvin didn't say what values to use for the line loss. I would like, when they get ready to build some of these lines, to supply the line losses at very much reduced figures, under the figures they give. The figures which we use in California are practically one-half the line loss per kilowatt hour that they use in this paper. That, I think, will make a material change in

the results. The cost per kilowatt-hour of line loss decreases and not increases with length of line.

A diagram similar to theirs on regulation has been in use in my office for a good many years, and a similar diagram was recently published in the *Electrical World*. The fundamental basis of it was given in May, 1900, in the A. I. E. E. JOURNAL.

E. A. Loew: I wish first to reply to Mr. Carey's question with reference to the 90 per cent corona factor. I may point out in answering that we don't care what factor is used, so long as he uses some factor, be it unity, or a little more, or a little less. Every engineer is free to choose whatever value seems best. It doesn't affect the general scheme outlined. It is difficult for me to see, however, how you are going to increase the economy of a line by increasing the voltage above the corona value, because the corona loss is proportional to the square of the overvoltage, and as the voltage is increased above the critical value the loss soon becomes excessive. We have made no test to determine whether introducing corona would yield a value for the most economical voltage, above the critical disruptive value for the conductor used. It hardly seems necessary to make such a test.

If I interpret Mr. Baum's statement correctly, he made the assertion that we predicate a voltage which is proportional to the length of the line. That is exactly what we do not do. If Mr. Baum will examine equations (**21**) and (**64**), he will find that there is no such thing involved. In equation (**64**) the length of the line is involved only as a factor in the last term of the denominator, and then only to the extent of the 6th root of $(1 \div L)$. In the numerator is involved the root-mean-square kw. transmitted over the line to the one-third power. Therefore, the amount of power that is transmitted over the line is by far the greater influence, and the length of the line has very little to do with determining either the conductor diameter or the voltage used.

In other words, if one were to transmit 100,000 kw. for example, over a single line 100 mi. long, it is quite likely that the voltage required would be higher than for 50,000 kw. transmitted over a 200-mi. line.

A statement was made relative to the assumed power loss. I wasn't very sure what the speaker had in mind, but it is true and it is stated very emphatically in the paper that any assumption as to power loss on a transmission line as a basic criterion upon which to determine the proper design of the line is more than likely to be erroneous. It so works out in these problems that we have used as illustrations, that the percentage power loss increases with the length of the line. In other words, an economic line for 100 mi. would probably have a power loss, (an average power loss) of about 4 or 5 per cent. The 200-mi. line might have 7 per cent, and the 300-mi. line probably 9½ or 10 per cent, but the loss does vary with the length of the line.

With reference to the diagram which is alleged to have appeared in 1900, I wish to state that many diagrams have appeared from time to time, among them one by Mr. Baum. The diagrams in this paper have, we believe, certain new and valuable features. We offer no apologies for the diagrams.

IMPROVEMENT IN DISTRIBUTION METHODS[1]

(HOOD)

SEATTLE, WASHINGTON, SEPTEMBER 17, 1925

R. E. Cunningham: I have particularly noted the first paragraphs of Mr. Hood's paper regarding the necessity of thoroughly grounding secondaries and I want Mr. Hood to know that I concur with him in his statements.

I believe that too many of us have been content to drive a pipe or two connected to each secondary system and call it good enough. We all know what may happen to such grounds, particularly in dry districts. I think we should arrange through local ordinances to have a ground connection made at each customer's service which would be installed at the same time the house is wired by the contractor. This should be a water-pipe ground.

Now, as to using a common neutral, Mr. Hood, no doubt, has a condition where, as he has stated, his plan has worked satisfactorily. Whether it would work under conditions obtaining in Southern California is a little doubtful. We have a long, dry season and a good ground is hard to get; in some cases it is impossible. There are very few districts where we have continuous water-piping systems and in some cases cement is used in making the joints in the pipes.

Thus far on our 4-kv., four-wire systems we have adopted the practise of grounding the primary neutral at frequent intervals, generally by the use of a driven pipe. We have not tried the plan of using the same wire for a secondary neutral.

I might say that in most cases we do not have secondary systems continuing throughout the primary circuits, so that possibly there is not the same opportunity for economy as exists with Mr. Hood. With the system as I stated, using the driven-pipe grounds connected to our neutrals, we have had a number of cases during the dry season when the phase wire has fallen and lain on the ground without kicking out the circuit breaker at the station. We are particularly concerned as to how to take care of such a hazard.

We have recently built a new substation in a district where the system was being changed over to 4-kv. four-wire and are trying out the scheme as shown in Fig. 1 herewith. Here the neutral wire is isolated from the ground except at the station and there the connection is through a current transformer, the secondary of which is connected to an ammeter and relay. This relay in turn can actuate an alarm bell. Any current in the neutral due to unbalanced load will not indicate on the ammeter or cause the relay to function, but any current returning to the station from a phase wire which might fall on the ground must flow through this current transformer.

The current transformer is provided with taps and the relay so adjusted that it will operate when one ampere flows through the ground connection. Tests have been made which show that about that amount of current would flow when a coil of bare wire connected to a phase wire was thrown into a patch of green grass at a distance of about one mile from the station. Normally adjustments are for a much higher current so as to protect against a full ground and then once each hour the operator makes a test using the one-ampere adjustment.

We hope with this device to discover cases of phase wire on the ground under such conditions as not to cause sufficient return current to trip the circuit switch.

I would like Mr. Hood's advice on our situation and also wish to inquire whether with a phase wire down he usually gets enough current through the ground on his 4-kv. circuits to release the circuit switch.

E. R. Stauffacher: The ground relay mentioned by Mr. Cunningham will ring an alarm only when a current of one ampere or more goes back to the station from the line lying on the ground, whereas, our test indicates that only 0.3 or 0.4 ampere actually flows back to the station when a line is down on a 4000-volt distribution circuit about one mile from the substation. This, or course, applies to the dry soil condition. The equipment would indicate properly and give an alarm if the wire happened to be lying in green grass or in wet soil or against a green tree. However, there is every reason to expect that it will be rather difficult to develop equipment which will indicate when a line is lying down in dry soil or on a concrete or asphalt pavement. This leads me to believe that it would probably be better practise to install numerous grounds along the distribution line in addition to the ground at the substation, and to make every effort to see that the circuit breaker tripped out in case a wire dropped to the ground, rather than attempt to develop some type of ground detector which would indicate this hazardous condition.

1. Complete paper available in pamphlet form only.

C. A. Heinze: In Los Angeles, we have made use of grounds to water pipes for some years past. Our method is to select at least three services on each secondary and ground the neutral of each service to the local water pipe on consumers' premises.

It seems that ten or fifteen years ago the water department of our city experienced considerable trouble and difficulties with electrolysis. I imagine that a number of members know the full meaning of that word when applied to water systems, and the difficulties with electric railroads. To protect itself, the water department in Los Angeles constructed mains with cemented joints, thus preventing the possibility of getting a good ground by attaching directly to the main itself. However, on a three-wire service if we can obtain permission from the consumer, we bring down the neutral, connecting it directly to the water service. For mechanical reasons sometimes we use a piece of conduit, bonding it at each end.

I am a bit surprised to learn that Mr. Hood would like to have us go back to the multiple street-lighting system. It seems to me off-hand that we would be taking a step backward. I remember quite well that years ago we all, more or less, had multiple street-lighting systems, and we gave them up for the supposedly more efficient series system. Now, I find there is a tendency to go back to the multiple system again. I don't know whether the telephone engineers have had anything to do with this or not. At the same time I can't believe that it is a step in the right direction. Mr. Hood proposes and does install a contactor for connecting each lamp to the secondary bus nearest to the location of the lamp. From his paper I gleaned that it will require twelve watts of energy to keep this contactor energized during the daylight hours, and of course, during the hours when the lamp burns, the contactor is out of circuit or de-energized.

In Los Angeles, excluding the ornamental post lamps, we have 10,000 street lights of the suspension type. Now, if the contactor were to be provided for each one of these lamps in order to operate it on a multiple system as recommended by Mr. Hood, our loss in energy, valued at one cent per kilowatt hour would amount in a year to practically $7000. I don't know what Mr. Hood's company receives for energy for street-lighting purposes in his city, but surely none of us in the West are making sufficient money on street lighting to stand a yearly loss of any such amount; in our case, amounting to $7000.

I can't see what the future holds for us if we go to a multiple system. I would like Mr. Hood to explain the reason for going to the multiple system. I have always been given to understand that the multiple lamp, toward the end of its life, greatly decreases in candle-power, while the series type tends to burn at full candle-power until it burns out. I feel that this will result in a large number of lamps being continued in service at reduced candle-power and not being replaced until they actually burn out, resulting in decreased illumination on the streets. I think we, as utilities, should strive to give the public all they are paying for and the best street lighting possible.

M. T. Crawford: I notice that the neutral return path described by Mr. Hood is apparently largely in the secondary neutral grid. I would like to ask if single-pole switches are used or three-pole switches on the outgoing feeders at the substation. It would appear that if single-pole switches were used and single-phase short circuits occurred, opening one or two switches, the neutral would be called on to carry the full-load current of the phase which remained in service, greatly increasing the duty of the neutral path, and I should think increasing the troubles that might come from using only a relatively light-capacity neutral grid.

Rather extensive use is made of fuses in the secondary main for sectionalizing in case of trouble. I would like to ask Mr. Hood what method he has for finding out when these secondary sectionalizing fuses blow. If secondary sectionalizing fuses should blow and no knowledge was had of the fact, they might stay open for some time and interfere with the proper interchange of load current.

Mr. Hood refers to the fact that the primary-neutral return current sometimes will split and take the paths of the secondary outside wires, rather than all go through the common neutral. I would like to ask if he has made any test which would determine whether or not this disturbs the voltage regulation on the secondary at such points. It would seem that it might have considerable effect on the voltage drop on the secondary bus and would affect the consumer's service.

In regard to the underground system, I would like to ask if Mr. Hood has experienced any operating difficulty in connection with the relay contacts. On the underground distribution system in Seattle where a large number of power-directional relays are installed, we have found it necessary to periodically inspect and clean the relay contacts. The gases and other substances in the subways appear in some way to cover these contacts so that they do not always function.

D. K. Blake: I find a large number of people who are strongly in favor of the common neutral and just as many who are strongly opposed to it, but the chief cause for opposition seems to be the telephone interference.

As to the multiple lighting circuit, there are a large number of eastern companies who are going into that, studying it and applying it. I was very much surprised to find in Denver that the business section was supplied with multiple circuits with cascade pilot-wire control.

Mr. Hood referred to his polyphase secondary network for the business section which is a seven-wire system. There is a somewhat different type of system used by a large southern city of about 200,000 population. They have the same idea, that is, they do not want to supply an off-standard voltage to their customers' devices so they take the secondary winding of the transformer and extend it to 133 volts, which gives 230-star volts for the motors, and of course, a seven-wire system.

As to the matter of neutrals carrying load current, you might be interested in knowing that there is one large company which makes the practise of connecting distribution transformers from one wire to the grounded cable sheath and in that way they have the cable sheath carrying a number of amperes of load current.

D. I. Cone: As already stated, the subject of distribution systems is of great interest to telephone engineers: one item in particular in Mr. Hood's paper presented today is of importance from that point of view; that is the question of the use of a common neutral for the primary and secondary ground connections and, also, the question of the multiple grounding of primary neutrals. I shall not undertake a discussion of that problem because we have attempted to cover the subject pretty thoroughly in the paper by Dr. Trueblood and myself.[2]

Mr. Heinze referred to the interest of the telephone engineers in the street-lighting problem. There is a paper by Mr. McCurdy which discusses series street-lighting systems from this point of view[3]. As to the multiple street-lighting arrangement, I think, without having had experience with it, that the multiple scheme would make coordination with the telephone plant much easier.

G. H. Smith: I would like to say a word in discussion of Mr. Hood's multiple street-lighting system. We have been living with an overhead series system in Seattle for twenty years and for the last five or six years we have been trying to find some way to dispose of it. The underground lighting

2. Power Distribution and Telephone Circuits, by H. M. Trueblood and D. I. Cone, A. I. E. E. Journal, December, 1925, page 1353.

3. Induction from Street-Lighting Circuits, by R. G. McCurdy, A. I. E. E. Journal, October, 1925, page 1088.

system in Seattle is multiple, and the lamps are low-voltage, fed by transformers in the pole bases. We are averaging about 4000 hours' life on these lamps. It is hard for us to believe that we should use a 120-volt multiple lamp for that service athough I believe that is the lamp manufacturer's recommendation. We hope before long to install an overhead multiple lighting system very similar to the one described by Mr. Hood. We have been working on it for years, and believe that it will justify itself from the standpoint of safety alone. Also, our figures seem to show that it will be fully as cheap and more reliable.

S. B. Hood: Mr. Cunningham has brought up the point as to whether the common-neutral system was suitable for California. I think probably the best way to find out would be to try it. The main thing in the common-neutral system is to have sufficient neutral copper so that the earth does not form a part of the return, not an essential part. Therefore, if the air conditions are very dry, all that is necessary is to equalize the potential between the neutral system and the earth, so I rather think that the point of safety would be just about on a par with the dryness of the earth. If the earth is absolutely dry, it is a perfect insulator, so if you maintain your neutral at earth potential at the interconnection, you never would get any appreciable difference between that neutral system and the earth, even though the earth conditions give very high resistance.

On the question of the opening of the circuit breakers in case of a fault to ground, I suppose what Mr. Cunningham meant by ground was the conductor lying on the ground. My experience has been that it doesn't make any difference what kind of a system you use, isolated-neutral or common-neutral, you cannot depend on opening a circuit breaker on contact to ground. The artificial ground connection such as a driven pipe, will not have less than 100 ohms resistance. Now, you can readily see that 8 or 10 ft. of 3¼-in. pipe, will not give a good ground. The contact resistance of a wire on the ground may be up in the thousands of ohms. So I don't think it makes any difference; you can't depend on opening the breakers through accidental contact with the earth.

Mr. Heinze brought up the question of the individual house grounds, and the difficulty of getting continuous grounds through the water main. I think that is probably common all over the country, possibly not to as great an extent as in Los Angeles, but you get the benefit of the buried pipe which forms a service pipe from the main, including the section of main in which that service pipe is tapped. So in the aggregate you have a fairly good surface of water pipe in contact with the earth, certainly much better than you could ever expect by an artificial ground. When you interconnect all of those grounds by a system neutral, you can count on pretty good protection.

I am sorry I can't agree with Mr. Heinze about the multiple system being a backward step. We think it is the greatest step forward we have ever made. I have felt for a great many years that the practise of running series circuits, which may have potentials up to 6000 volts, through alleys, and out to every street corner, networking your whole area much more highly than your primary circuits can, comes pretty near to being a crime, and there are probably more accidents to the public and to the utility's operating staff through those high-voltage series circuits, than any of the other circuits you operate. The only trouble in the past has been to get the same efficiency in transmission with the multiple system. That can be solved by utilizing the distribution transformers, and the relay control system. Our experience with the maintenance of candle-power in the lamps has been remarkably good. I have always criticized the series system on a basis that the lamps, unless you break them up, will get so dim that you can't see whether they are burning or not.

Regarding the contactor losses in the multiple system, I think you ought to get the right point of view. You must consider that the series constant-current transformer at best will have only an efficiency of about 85 per cent, whereas the contractor uses 12 watts only for initial action, and as soon as the core rises it chokes the consumption down to 8 or 9 watts. That represents less than 2 per cent on a 500-watt lamp, and in a great many cases a group of five or six lamps may be found on one contactor. You can readily see the contactor losses are almost negligible compared to the losses in the series type of transformer.

The principal advantage we found in the multiple lighting system has been the better service during storm conditions. It frequently happens during a bad storm that lamp outages on the series circuits will run 17 to 20 times as high as on the multiple. As soon as the storm starts you will see the multiple lamps winking like stars all over the city. It can readily be seen with the series system that each accident or effect of the storm which has lit the multiple lamps would have put out of business the series type of circuit.

The question of maintained candle-power is one which I think we shall have to leave to the engineers of the lamp association. We picked the series type of lamp and adopted the multiple system, believing that the series lamp was the best of the two lamps. Now, they tell us that the series lamp was a poor lamp at its best, and we should use the multiple lamp, so I don't know which is right. Experience will have to show. I think, however, that one feature in favor of the series type of lamp particularly in our large cities, is its longer life. They claim series lamps used on multiple system will give 2160 hours' life. We are getting 3000 hours on ours and better, and very well maintained candle-power. They also claim the multiple type of lamp is good for 1300 hours. My experience with the large systems is that if you get 1000 hours life out of it you are lucky.

Now, where you have cars parked along the streets all day and most of the night, when are you going to get a maintenance car up to the ornamental lamps? The men must go around before sunrise, and even then you will find many cars.

Mr. Crawford asked whether we use single-pole or three-pole switches on our feeders at the substations. Originally all our lighting feeders, before we converted to the common neutral, were the two-pole. So the only change we made was to change the original double-pole switches; the two poles were put in series giving twice the breaking capacity. Those circuits, however, were almost entirely lighting circuits and we found that the action was substantially that of a one-wire single-phase circuits. They didn't act as three-phase circuits at all. However, all our three- phase power circuits had three-pole switches, and as we cut to combination feeders, we found the single-pole switch had no advantage, due to the fact that among the other peculiar things we do, we always ground the neutrals of our three-phase power transformers. When you get a single-phase short circuit, the closed secondary delta transfers the short circuit to a very considerable extent to the other two phases, so that all three switches, would go out in the same way as though they were on a three-pole switch. For that reason, as we rebuilt our substations, we conserved substation space by putting in entirely three-pole switches. In the modern substation with automatic closing equipment, it is the fact that almost always a circuit will not lock-out but will burn the fault off.

The matter of locating blown section fuses is largely checked up by periodic inspections made just before the fall peaks. During the summer season most of the load in the interconnected districts being residential load, it doesn't make much difference whether those fuses are in or out, except in some places where the range load is heavy. We make careful inspection just prior to the fall peak, and from then until we pass the overlapping period, the spring of the year, we depend on the customer to let us know when those section fuses are out. Generally he doesn't waste much time in doing so. In other words, our transformers

will carry the load with those fuses out as well as with them in, but the regulation would be very much poorer; therefore, we almost invariably get a complaint from a customer when a section fuse is out.

We have never had any trouble with the effect on secondary regulation caused by flow of current in the neutral. There is under certain rather abnormal conditions a tendency to unbalance voltage, but you must have a very abnormal condition to bring out that effect.

Regarding Mr. Crawford's question as to relays in the underground a-c. system, our condition is possibly just a little different from what he may have in mind in that our transformer vaults are to all intents and purposes substations. We don't have the dampness and the gases found in an ordinary manhole vault. We are particularly fortunate in Minneapolis because we can put vaults under the sidewalk, and they are just as dry as the basement of a building; in fact, they are virtually the front of the basement. We use the same type of relays and equipment as used in the ordinary substation, and they are inspected periodically; in most cases once a week.

In Mr. Blake's remarks, he referred to a system in the South which used 133-volt transformers. That is the type of transformer with the 133-volt secondary tapped at the 115-volt point. We had considered that, but the objection we saw was that it made a semi-special transformer which is objectionable from the standpoint of simplicity in warehouse stock were it is necessary to stock one type of transformer for overhead distribution and another for underground. If the underground required a special type of transformer, probably that tap would be all right, but in our case we have adhered to standard equipment throughout.

THE STUDY OF IONS AND ELECTRONS FOR ELECTRICAL ENGINEERS[1]

(Ryan)

Seattle, Washington, September 17, 1925.

R. W. Sorensen: Professor Ryan says, "There are two varieties of electrons, positive and negative." On this he can find much authority; in fact in his book, "The Electron," Dr. Millikan speaks of positive and negative electrons, but I much prefer in this particular to follow the practise of those who define the electron by saying it is a cathode particle such as is found in the cathode rays. I choose this path of thinking about electrons because we all know something about cathode rays. These rays have been found to be made up of negatively changed particles, and the particles are called electrons.

This definition makes the electron a single individual, always negative, rather than twins, one positive and one negative, and it is, as a consequence, more easily recognized. If the electron cannot be a twin, we must provide it with an affinity from which it wishes never to be separated, and in this form of nomenclature the term proton has been applied to the same individual that Professor Ryan has called the positive electron.

More frequently than not, these electrons and their protons are found in large groups, but, in the case of the hydrogen atom, they are alone, this atom being made up of one electron and a single proton nucleus. That points out one question to which we might refer in Professor Ryan's paper where he stated, I believe, that the positive electrons were not found alone; but this is the one exception. If one of these hydrogen atoms encounters a disturbing influence, such as an electric field, powerful enough to detach an electron, the electron becomes free and there is left the single proton.

Proceeding in the direction of complexity of structure, we could discuss the helium atom which has two electrons attached to a nucleus that appears to have four protons.

When one or more of these electrons or negative particles is taken away from an atom the remainder behaves in such a way as to indicate that it has a positive charge, and is known as a positive ion. Thus atoms become ions when they have a deficiency or excess of electrons.

I see no reason why protons as defined cannot exist in a free state in a hydrogen arc, but it is, of course, true that compared to the number of times one can find free electrons, such an occurrence is very limited.

I had planned to question the statement that "under all ordinary conditions approaching quiescence, free electrons adhere to atoms, otherwise neutral." But now, although a number of physicists think they are free, I am inclined to think that we shall get into less trouble if we take Professor Ryan's statement that these electrons are likely to attach themselves to neutral atoms, making them negative ions.

Something is said about electron travel. In regard to that, when we measure an electric current as so many amperes we are measuring the sum of the positive and negative ions passing through the ammeter.

I should like to suggest that perhaps as engineers we would clear up Professor Ryan's statements as to the movement of electrons, by saying that the electrons or ions may be moved mechanically, electrically or magnetically; that is, you can move them by mechanical means by placing them in what we call electrostatic field, or in a magnetic field. I know that is exactly what Professor Ryan intends to say, but I think it would be better to say magnetically rather than electromagnetically.

On the second page Professor Ryan has divided conduction into three groups. I think we should add something to these. An electric current made up of these ions or electrons will also travel through a vacuum, and I do not believe that this has been included in these three sections. Also, I am not quite sure that these three groups as listed show conduction through an arc.

To the paragraph at the top of the second column on the second page I am inclined to add the idea that every atom has electrons; therefore, how can one have a fluid which does not have atoms and hence does not have electrons? Correspondingly how would it be an insulator under Professor Ryan's definition?

Considering practical engineering application, I am one of the many who have a feeling that air, pure and unadulterated, if not a nearly perfect insulator, is at least a pretty good one and one which will serve us for a long time. In the final analysis, all our transmission lines are air-insulated, the porcelain bead chains with which we decorate our transmission towers being, after all, only decorative suspenders which serve to keep the lines from falling. The insulator is the air.

I think the reason Professor Ryan and I differ in this is because he says a thing is not a thing unless it is at least 99.44 per cent pure. Air, then, is an insulator just as oil is an insulator. If we introduce into the air, free electrons or ions, the air as an insulator becomes defective in exact proportion to the amount of impurity introduced. In undertaking our engineering problems we call oil an insulator. It never is a perfect one and it ceases to be an insulator at all if moisture is added to it, its value as an insulator decreasing in proportion to the amount of water added.

I might also add that in the sense which Professor Ryan has spoken of an insulator, a vacuum is not an insulator. Current can and will go through it. To my way of thinking, a high vacuum is an insulator, but it is not a perfect insulator; therefore, Professor Ryan says it is not an insulator.

When two conductors are brought very close together, a potential of 1,000,000 volts. per cm. or even greater potentials may be required to break down the gap. Also, cold electrodes in high vacuum require potential gradients of this magnitude as ionizing potentials, but charged electric conductors in air at sea level and separated practical distances will arc over one

1. A. I. E. E. Journal, September, 1925, p. 964.

to the other if the potential gradient in the air between them is 30,000 volts per cm.

However, on this point I must assure you that though we are using different words, Professor Ryan and I understand each other thoroughly in this matter, and in conducting experiments involving these things, we would use in many cases the same strategy and anticipate the same results.

C. E. Magnusson: There is, one factor—in fact a vital factor in the electron theory—the physical characteristics of which are seldom discussed while the attention is focused on the several forms of mass units involved. I refer to the electric charge. What is the innate nature of positive and negative charges, which take possession of, or are possessed by, electrons, ions, protons, corpuscles, or by whatever name the mass units may be designated? How can the charge, if located on or attached to an electron or other mass unit of definite size, produce action at a distance or be attracted or repelled by other charges attached to far away mass units? What is back of Faraday's lines or tubes of force? May I ask Professor Ryan to give us his concept of the electric charge?

C. L. Fortescue: I think one of the reasons why electrical engineers have difficulty in following and applying the electron theories is because it is the first time they have come up against the subject of statistical mechanics, a subject with which physicists have become very familiar in their study of the dynamic theory of gases.

Now many laws of physics, dynamics and physical chemistry were found before the kinetic theory of gases was well established, and these laws prove to be true under practical conditions.

Electrical engineers have been accustomed to think of air as an insulator which breaks down, under ordinary conditions, at about 30,000 volts per cm. This, of course, is a very convenient way of looking at it, but we know by the electron theory that this isn't at all true except under certain specific conditions.

The electron theorists tell us that the air will break down at any point where the rate of ionization and the rate of recombination are equal. I believe the rate of recombination depends upon the mobility and the rate of ionization depends upon the density of the air and also upon the total value of applied potential or the difference of potential between electrodes; but we have two quantities there that have to be taken into account. As a consequence we find for a very small separation, as Mr. Sorensen points out, a breakdown strength of the order of 1,000,000 volts per cm. In a larger space the breakdown strength of the air becomes less and less. In the ordinary spaces the engineer uses, we find it averages around 30,000 volts per cm.

In Professor Ryan's paper, I was a little disappointed when I read his remarks about the three sorts of insulators. Unfortunately we are likely to generalize and think of these things practically as hindering our methods of insulation. For instance, Professor Ryan makes his statement in such a way that one would think, reading it superficially, that barriers were absolutely indispensable in connection with all insulators. We know by actual experience if proper care is taken to prevent the formation of corona, or putting it in terms of the electron theory, when local ionization is avoided, we can use air without applying barriers, and the strength of the air will follow the avarage law which I have mentioned, breakdown taking place at about 30,000 volts per cm.

Certain conditions occur when the bounding surface between solid dielectric and air apparently does not follow the law of breakdown in air. I think these discrepancies have been attributed to the effect of the absorption of gases or moisture on the surface, but if you have a perfectly clean surface of proper conformation, the path along the surface will have the same breakdown strength as the air has.

I should like to ask Professor Ryan to clear up this difficulty in the interpretation of this paper. We are sure as engineers that the air is still a medium for insulation.

F. G. Baum: For many years (since 1911) Dr. Ryan has exhorted us to study the electron. I am here as a missionary today to try to help show the importance of studying the electron. For many years the subject of electrostatics has been taught in schools. In my opinion, there is no such subject as electrostatics except as you get down to an extreme vacuum where you have no ions injected into the vacuum; otherwise you have "electron mechanics," and I believe in a very short time you will find that our textbooks will be rewritten and the term "electrostatics" practically eliminated. It is wrong and we must get another proper term and realize that we are dealing with objects moving at very high speed and causing entirely different conditions from those which we thought true when we studied electrostatics.

Ordinarily, we take two bodies and draw lines between and say that is an electrostatic field. It is an electrostatic field only because electrons are moving from one of those bodies to the other; and our higher voltage insulation problem is dependent on a knowledge of handling this electron flow.

H. J. Ryan: Replying to Professor Sorensen: I can accept, if necessary, the use of *proton* in lieu of *positive electron* as proposed by some physicists. It is simply a choice of terms. Personally, however, I like Doctor Millikan's use of *positive electron* to emphasize the fact that all matter is substantially made up of cathode and anode particles. As implied, it is true that experimental facilities are as yet more abundant or convenient for the liberation of cathode particles than for anode particles. These cathode and anode particles surely are twins of just the character referred to. They carry elemental charges equal in amount and opposite in sign. The positive electron or proton is much smaller in diameter and has a correspondingly greater mass than the negative electron. The same elementary electric field or charge centers in the electron whether positive or negative,—the one and only known difference being that of direction or polarity. I do not feel that the use of the term "proton" is adapted to the presentation of these facts as well as the term "positive electron." It is helpful to have been reminded of the stripped hydrogen atom which can be produced and which must behave as an isolated positive electron, proton, or anode particle as we may variously call it.

I quite agree with the idea put forth in regard to the movement of ions and electrons mechanically, electrically or magnetically. However, it should be remembered that they may be moved also by any combination of these agencies. For example, ions in the air that is blown along between the poles of a magnet and between metal plates maintained at a difference of potential, will be moved mechanically, magnetically and electrically. It may be that it is not helpful to compound these terms and say that the ions were moved electromagnetomechanically. I am quite agreed to say that they were moved electrically, magnetically and mechanically.

I am glad to accept *vacuum* for a place in the list of electrical conductors. I had left it out originally because in the first place a vacuum is not anything, anyway in the ordinary sense and, therefore, can not assist or hinder the migration of ions or electrons; in the second place, as Mr. Wood brought out in the talk referred to, as soon as ions or electrons are admitted to the vacuum it may in a sense be thought of as having ceased to be a vacuum.

I can see no difficulty with the statement "No fluid of any sort pervaded with a supply of ions or electrons can properly be regarded as an insulator. Correspondingly, every fluid in which ions and electrons are absent must function as an insulator." Of course, each molecule of neutral transformer oil is made up of complete or neutral atoms that in turn are made up each of an equal number of positive and negative electrons bound together, forming neutral aggregates. Such oil is not a supply of ions and will not conduct under an impressed electromotive force of moderate value. If, however, the oil con-

tains impure water in suspension it is pervaded with a supply of ions and will conduct.

I cordially admit the powerful revulsion of feeling that must come to one when first confronted by the fact that it is the wall of the metallic conductor when immersed in air that is really the insulator and not the air. Take away the air, as one may do in a vacuum, and the conductor will be insulated just as well as before. This is the fact that made me doubt the wisdom of putting "vacuum" in the list of conductors. It does not really matter, though, as long as we can agree as to the circumstances in which it does or does not conduct. Years ago, when the idea prevailed in my own mind that air is one of our best insulators, with dielectric strength greatly enhanced by compression, I undertook to provide a powerful dielectric by means of air compressed to 1500 lb. per sq. in. I was greatly perplexed by the results because I was wholly unaware of the fact that air will permit ions to pass through it freely if one will but provide a source thereof, such for example as a hot carbon electrode. We did not know then, as we know now, that in all ordinary circumstances electrons cannot escape from the wall of a conductor which is the basic reason why we were made to believe that the air was the real insulator. Furthermore, we did not know then, as we do now, that at extraordinarily high electric intensities at the surface of an electrode conductor (1,000 kv. per cm. approximately) electrons or ions will escape from the wall of the conductor and be driven freely through the air to the opposing electrode where they will be discharged. With a knowledge of these facts twenty years ago we would not have been perplexed by the anomalous behavior of air as an insulator when put to a real test.

I cannot agree that it is a matter of degree to be covered by such a small item as the departure of 99.44 from 100. It is not a question of purity or impurity any more than it is in the case of water. Water will conduct as long as it has ions suspended in it. Being a fluid it ceases to conduct only when the supply of ions has been eliminated. And this will cover also the reference to oil.

Doctor Magnusson asks the question "What is the innate nature of positive and negative charges which take possession of or are possessed by electrons, ions, protons, corpuscles or by whatever name the mass-units may be designated?" This question and the form in which it is put are helpful even if one has not a ghost of an answer. I can only discuss this question, I cannot begin to answer it. I can only offer what appears to me to be a reasonable conjecture in regard to the perhaps most important attribute of the electron. This is that all electric fields are made up of unit-fragments alike in constitution. Each field fragment terminates on an electron from which it extends radially and expands uniformly, and so far as we know, indefinitely. These field fragments are the same, whether positive or negative, differing only in polarity and in radius of the electron surface at which the field terminates, being much smaller for the positive electron which must, therefore, have a correspondingly greater mass, the measure of the energy that was used in the extra concentration of the field. Whatever else they may be, electrons are surely these field fragments. All greater electric fields are merely aggregations of these unit-field fragments. The electric intensity through any field volume is the vector sum of the radial field fragments attached to the electrons that constitute the charges to which the field is attached. Maxwell understood the composition and resolution of electric fields and taught us to locate "tubes" of electric force by drawing diagonals through the parallelograms that are formed by the radial lines which represent the electric fields that extend uniformly in all directions from charges located at a point. It is the vector composition of superimposed fields terminating upon the positive and negative electrons that forms the "tubes of force" of an electric field. It is in the presentation of these facts that I find the term *positive electron* more helpful than *proton.*

It is also helpful to have Mr. Fortescue emphasize the importance of *statistical mechanics.* I trust that all who are interested in the new knowledge will read thoughtfully what he has said. He also refers to the extremely short space that must exist between metal electrode faces before electrons will leave them and the vacuum, or gas-filled space between them, will become conductive. If the fact is allowed to stand in that light I fear we shall give our more general audience the impression that this action is the result mainly due to the close proximity of the metal electrode-faces. In fact it cannot primarily be due to the nearness of such faces as Hayden and Steinmetz have shown in their A. I. E. E. paper on the dielectric strength of the vacuum.[2] The preparation of my paper was only possible by the use of old terms with new or modified meanings. I had to count, therefore, upon precisely such disappointment as that of Mr. Fortescue because I have referred to air as a conductor instead of as an insulator. I have no thought of proposing that we stop calling air an insulator. What I do want to see established is a better understanding as to how it can be made to conduct abundantly. With that, and with more of a background in the subject which will come with experience, the choice of terms with no doubts on important difference, will be readily accomplished. I am a hearty advocate of the high value of the *Fortescue principle* wherein air insulation barriers of powerful solid dielectrics are applied, having boundaries coincident with those of the tubes of electric force in the air adjacent. Such barriers displace the air in regions of dense electric fields that would otherwise ionize and afford prolific conduction. We do not differ as to the facts and in the end we shall have put new meaning into old terms or adopted new terms by which all who use them will apply helpfully the new knowledge of these things.

Mr. Baum has declared rightly that electrostatics are hopelessly inadequate for understanding and for effective control of electrical states and actions. This I know to be the case even though we cannot agree as to facts when he says that a quiescent electric field between two charged bodies is such "because electrons are moving from one of these bodies to the other." Of course, this brings us face to face with the age-long problem of "action at a distance" and my question to myself is: "has Mr. Baum made some progress toward the definition and solution of that problem?" Most of us have not,—we face a high wall and cannot see what is beyond. To me the static electric field between two bodies is the composition of the two field aggregates of opposing polarity that terminate on the corresponding free positive and negative electrons that are bound to the surfaces of such bodies.

SOME FEATURES AND IMPROVEMENTS ON THE HIGH-VOLTAGE WATTMETER[3]

(CARROLL)

SEATTLE, WASHINGTON, SEPTEMBER 17, 1925

R. W. Sorensen: When I first saw the diagram of connections shown in this paper I was awed by the apparent amount of large apparatus necessary to construct such a wattmeter. However, I have had the opportunity to stop at Professor Ryan's laboratory and became acquainted with the equipment described in this paper. An acquaintance with the equipment eliminated the impression of bigness which I had received from the diagram and which was perhaps due partly to the high voltages which the equipment will measure. In place of this impression I received a definite picture of the cleverness exhibited by Mr. Carroll and Professor Ryan in handling this problem. For example, the transformer of three windings and a split core, which seems in the diagram to be so large, is actually very small, in fact, it can easily be held in one hand.

2. High-Voltage Insulation, by J. L. R. Hayden and C. P. Steinmetz, A. I. E. E., TRANSACTIONS, 1923, page 1029.

3. A. I. E. E. JOURNAL, September, 1925, p. 943.

The water column, about 16 ft. long, is so arranged between the shielding plates at the ends as to occupy a space approximately 3 ft. in height. The small transformer and the indicating instruments are all mounted on a small table surrounded by a wire cage the dimensions of which approximate 4 ft. high, 6 or 8 ft. wide and perhaps 12 ft. long.

With this knowledge, I found it much easier to read the paper and appreciate what has been done in Professor Ryan's laboratory toward producing practical wattmeters and voltmeters for high-potential measurements.

H. V. Carpenter: Mr. Carroll mentions the integrity tests by which he established the fact that he was able to read with accuracy loads of a watt or two, with a voltage of 150,000. It seems to me the condition is so critical there that a word in relation to his method of establishing the integrity would be interesting. Also regarding the formula given for the resistance of the water column, I would like to ask whether he established it over a wide range of densities and for any materials except common salt.

J. S. Carroll: Ordinarily the man in a measurements laboratory thinks of errors in measurements as a few tenths of a per cent. However, in this case where we are measuring one watt of power at 150,000 volts and the apparent power is of the order of 6000 watts, I frankly admit that we are very well satisfied with an accuracy within 25 per cent of true values. As the load increases the accuracy greatly increases so that at 40 watts we expect the error to be not over two or three per cent. One of the integrity tests used is described in the present paper, that is the double-conductivity test. Another test is described in the Oct. 1924, A. I. E. E. JOURNAL in the paper on Power Measurements at High Voltage and Low Power Factor, by Carroll, Peterson and Stray. In this test a shielded resistance was inserted in the connection to the line, the value of this resistance was known as well as the line charging current through it from which the power absorbed by it was computed; this increase in power was also measured by the wattmeter. The agreement between the results of the two determinations was very satisfactory. The double-conductivity test was also used in connection with the above test.

In regard to Professor Carpenter's second question, I might say that we have so far tried only a common salt solution and have not gone farther than checking the formula given in the paper in an overall way for the purpose of finding any serious error. We measured the cold resistance of a solution and then calculated what the hot resistance of the water column should be, this result agreed very well with the value obtained under actual operating conditions. On some of these things we wish to make a closer follow-up as soon as we have time.

INDUCTION FROM STREET LIGHTING CIRCUITS-EFFECTS ON TELEPHONE CIRCUITS[1]

(McCurdy)

Seattle, Washington, September 18, 1925.

R. R. Cowles: The present tendency of the Pacific Gas & Electric Company is toward the use of small series street-lighting loops with incandescent lamps only. These series loops are 6.6-ampere and are supplied from a multiple-series constant-current transformer installed on the pole in the same manner as any other distribution transformer. These constant-current transformers are of the moving-coil type, fundamentally similar to those formerly used inside of stations. In size they range from 5 to 20 kw. each, depending upon the average size of the series incandescent lamps which are connected to the circuit. It is the aim to avoid long loops and to restrict the number of lamps per circuit to approximately 60.

These transformers are connected on the primary side to a 4000-volt, four-wire, three-phase, star-connected feeder circuit, said circuit being switched from the substation just as any other 4000-volt commercial feeder. Where the primary neutral is available no additional neutral is extended for the street-lighting feeder. Single-phase lines are run in various directions to supply the territory in the same manner as single-phase lighting feeders are branched from a three-phase feeder for commercial light and power consumers. The effect of the above arrangement is greatly to improve the reliability of street-lighting service through the elimination of long series loops and the resulting reduction in potential on these series loops. Multiple 4000-volt feeders have proven their reliability on the system of the Pacific Gas & Electric Company; hence no new features are involved in this type of feeder circuit. The constant-current street-lighting transformers are furthermore removed from the substations, thereby providing room for other apparatus which cannot conveniently be placed outside of the station.

The 6.6-ampere series street-lighting incandescent lamps are standard for 4000-lumen lamps and less. This is a slight departure from previous practise which indicated the desirability of using series transformers or auto-transformers with lamps larger than 2500 lumens. An improvement in lamp manufacture, however, has made it practicable to use 4000-lumen lamps at 6.6 amperes. Lamps larger than 4000 lumens are operated at 20 amperes, necessitating the use of series transformers or auto-transformers installed on the same pole or in the same fixture which supports the lighting unit. The film cut-outs are used with all 6.6 ampere lamps, operating without auto-transformer or series transformer.

The use of series circuits with currents in excess of 6.6 amperes has been considered by the engineering department of this company but no action has as yet been taken. Small series loops supplied from individual constant-current transformers, with lamps of higher intensity spaced fairly close, would permit of operation at 15 or 20 amperes if the characteristics of these lamps demanded it. Consideration should also be given to methods of switching street-lighting circuits from a remote point which would make possible the use of even smaller loops and considerably simplify the apparatus involved therein. There are a number of types of remote-control apparatus already developed and a number more in process of development. It appears to the writer that the use of radio control for this purpose might be worked out to a practical and economic application at some future time.

C. A. Heinze: Any power engineer who has had relations with the American Bell Telephone Company will notice that the telephone engineers all tell the same story. The main thought in all of their papers is cooperation between the power engineers and the telephone engineers.

I want to state, first, that the electric utilities want to cooperate with the telephone company. We recognize the fact that we have mutual services to render, but I should like to ask Dr. Trueblood just how far the American Bell Telephone Company will go in cooperating with the electric utilities in sharing part of the expense in safeguarding the telephone companies' equipment.

S. B. Hood: Mr. McCurdy recommends some of the usual remedial measures, principally isolating transformers. That is the 100-per cent remedial measure of telephone engineering, and in most cases it is a 100-per cent remedial measure, but in very few cases is it the measure which the power man wishes to adopt. It adds to the investment, adds to the losses in the system, more or less interferes with the regulation, and has a great many objectionable features.

Another recommended cure on series circuits is the straight-series lamp. That is very nice until we get to the higher candle-power. We are all developing "white ways" that require higher densities of lighting. Therefore, recommending the type of lamp which the lamp manufacturers are not prepared to furnish is looking far into the future.

It seems to me that possibly a better recommendation which they could make—particularly since Dr. Trueblood is so enthu-

1. A. I. E. E. JOURNAL, October 1925, p. 1088.

siastic over the multiple system—the better cure where inductive exposure is used, would be to change the lamps in that particular exposure to multiple, using a series relay for controlling. Of course, the recommendation for closed loops and balancing the lamp on a loop is very effective, but when you put a series street-lighting system with both wires looped on the same street, as far as the investment goes, it is practically getting back to a multiple system.

It seems to me, however, that in all these papers the indication is that no matter how far apart our past differences of opinion have been, we are all gradually coming closer together; the telephone men and power men are gradually getting down to a uniform system which I think is a very promising outgrowth.

R. G. McCurdy: The tendency of the development towards the use of smaller series street-lighting loops as described by Mr. Cowles in his discussion of the Pacific Gas and Electric Company's practises, from the standpoint of inductive coordination, is in the right direction. Because of the smaller number of lamps per circuit and since the constant-current transformer is closer to the lamp load, the length of any given circuit is much reduced and in case of failure of lamps equipped with individual transformers, the length of circuit upon which the harmonic voltages are impressed, and which may be involved in inductive exposures, is much less than when circuits of a large number of lamps are employed. In many cases also, this method of operation would facilitate supplying separately "white ways," where lamps of high candle-power equipped with individual transformers are used, and outlying sections where in many cases, only straight-series lamps are employed.

Mr. Hood referred in his discussion to the disadvantages of the straight-series lamp, especially in districts where high-density lighting is required. As brought out in my paper, however, it is very often the case that these high lighting intensities occur in the densely populated sections of cities and towns, where both the telephone and lighting circuits are in cable. In such cases the occurrence of "out" lamps equipped with these transformers is unimportant from the inductive standpoint. In other cases, where the "white-way" section may be of limited extent, it will often be practicable to connect the high-current lamps to circuits not involved in telephone exposures, having as far as possible, only straight-series lamps on the circuits involved in the inductive exposures.

Many of the difficulties of coordination discussed in the paper are inherent with the series system, and it would doubtless be less difficult to coordinate with multiple systems. The remedy suggested by Mr. Hood, therefore, of changing the lamps in a particular exposure section to multiple, using a series relay for controlling, would probably be an effective one. As far as the incandescent systems are concerned, however, it is felt that the difficulties existing with the series circuit, would be overcome by the use of a reliable form of cut-out with lamps equipped with individual transformers or auto-transformers.

DISTRIBUTION PRACTISES IN SOUTHERN CALIFORNIA[1]

(CUNNINGHAM)

SEATTLE, WASH., SEPTEMBER 18, 1925

F. O. McMillan: There are two questions I wish to ask. Mr. Cunningham states he is using some three-phase, Y–Y-connected transformers; are these core-type or shell-type and if shell-type, has any provision been made for the third-harmonic magnetizing currents in the transformers so connected?

S. B. Hood: In connection with the paper by Mr. Crawford and the one by Mr. Cunningham, we note that they are both using the ground as a stabilizing medium. I think the general tendency is indicated all the way through that that is what we are after. We are trying to stabilize our systems; not to use the ground as a conductor.

Mr. Cunningham brought up the point that in a great many cases the selection of the system was due to local conditions, and therefore, we shouldn't judge one system by that of another in another part of the country. I think that is absolutely correct. There is one point that I have heard in these discussions and papers, and I hear it all over the Coast—you question some particular practise, and instead of defending that practise from an engineering standpoint, somebody will say, "The state law doesn't allow us to do that."

I am wondering whether some of these state laws are not really placing an unjustified economic burden on the public. I think some of these laws probably were passed long before these newer developments were made. A notable instance of that is the law which apparently forbids the use of a secondary rack.

I don't think we pay enough attention to the esthetic appearance of our distribution systems. The secondary rack improves the appearance of the lines very much. Now, Mr. Cunningham, by using the one arm for both primary and secondary, with the pole intervening as a barrier, gets a relatively neat construction, but not as neat as the secondary rack. I think on the point of investment it would probably be an even break, but it seems that where the practise is quite common in one section of the country, and forbidden by law in another, there should be some equalization made.

There is another instance that is somewhat out of line with these papers: I have noticed further down the Coast there is apparently another state law which requires boxing-in an iron pipe on a pole. I have seen some poles where the box around the pole was larger than the pole itself. It is unfortunate that there are laws which require practises of that kind, such transgressions on the esthetics of construction, and sooner or later the utilities are going to be forced underground, before it is economically justified.

M. T. Crawford: Mr. Cunningham's reference to one-arm construction coincides very closely with our experience in suburban territory, where our primary is placed on one end of the crossarm and the secondary on the other. By placing the primary on the street side always, and the secondary wires on the property side, it makes for uniformity and obviates misunderstanding. By hanging the transformers on buck arms, crosswise of the pole, the primary leads come out straight and turn up and the secondary leads come out straight and turn up, making a very orderly arrangement.

In the city we have found it not so practical, due to the necessity of providing space for a number of feeders, and at times having polyphase primary and secondary requiring more wires.

R. E. Cunningham: The matter of third harmonic in the three-phase Y–Y transformer was brought up this morning. This was considered when we first thought of using this type of transformer. The high side of transformers is not grounded. The low side ordinarily working at 460 volts, we wanted Y-connected so as to ground the neutral and not have more than 260 volts to ground from any wire, as a safety precaution. Seldom, is there more than a single service to each transformer possibly not over 25 ft. of wire, so that the third harmonic has never caused any trouble.

Something has been said about the esthetic appearance of pole lines, and attempting to improve the appearance. At best a pole line is not a thing of beauty—we all know that. We can, of course, in some ways help its appearance. Our practise in this regard is, as far as possible, to keep pole lines, particularly in the residential districts, in the rear of property lines, and Fig. 4 of my paper shows such a line. In fact, none but the main lines need be along the streets, and we find this is a great help in keeping down agitation for underground lines in residential districts.

1. A. I. E. E. JOURNAL, November 1925, p. 1196.

ENGINEERING RESEARCH—AN ESSENTIAL FACTOR IN ENGINEERING EDUCATION[1]

(MAGNUSSON)

RELATION BETWEEN ENGINEERING EDUCATION AND ENGINEERING RESEARCH[2]

(SORENSEN)

AND

A NEW DEPARTURE IN ENGINEERING EDUCATION[3]

(PENDER)

SEATTLE, WASHINGTON, SEPTEMBER 17, 1925

L. N. Robinson: Professor Magnusson emphasizes the point that engineering courses should teach students to think if nothing more. If that is so, why do engineering curriculums, in general, not include courses in the mental sciences, particularly logic and allied subjects? However, it is not my present purpose to argue for or against the inclusion of any particular subject in the curriculums. What should be pointed out is that present conditions indicate a general lack of scientific treatment in the design of engineering curriculums as well as in their application.

We insist that scientific methods should be employed in designing engineering structures. Engineering students have an equal right to insist that scientific methods be employed in designing the curriculums of engineering schools.

When electric generating stations are designed by the same methods that are employed in laying out many engineering school courses, hybrid plants are produced in about the same proportion as our engineering schools turn out bond and automobile salesmen.

In designing an engineering structure, it is customary to decide first what is to be designed, whether it shall be a bridge, an office building, a locomotive or something else. Next we determine which parts shall be of steel, which of copper, etc., then we prescribe methods of fabrication and assembly. In other words, every step from the inception of the enterprise to the finished product is worked out with utmost scientific care.

Is this method followed in designing engineering curriculums and in training engineers? Before it can be said that engineering courses, themselves, are scientifically designed, we should at least first determine what the product of an engineering course should be. Then the elements that should constitute the course can readily be determined, with equal care to deciding how the courses shall be conducted.

Last June, at a commencement the chancellor of a university said that the world is full of people who know all about education except what it is for. This is a challenge to the engineering fraternity and to the engineering schools in particular; it demands a scientifically sound justification for our college courses and especially for our engineering courses. And, since we profess to be scientific in our engineering work, we should be better able than the humanists to answer the challenge. In doing so, however, we must be especially careful not to mistake consensus of opinion for sound scientific truth else we shall class ourselves with those who scoffed at Christopher Columbus because his views differed from generally accepted notions.

J. C. Clark: It seems to me that Professor Magnusson has lost a grand opportunity in his paper to bring out one of the main reasons why we should have research in engineering colleges. He has stressed the value of the educational aspect of research almost exclusively, and has pointed out that it nearly goes without saying that research has an indispensable part in technical education. Professor Sorensen also emphasized very strongly the educational value of research in the colleges. In other words, it is for the good of the colleges and the students that research is carried on in the colleges.

I believe that it ought to be pointed out by Professor Magnusson that the industry needs engineering research in the colleges as much, if not more, than do the colleges. As Professor Magnusson has so emphatically stated, it is true that the large corporations of today have millions to spend in research. They have large and well trained staffs to carry on industrial research, and they carry it on successfully and efficiently. On the other hand a great many of the smaller concerns have very meager appropriations with which to work and carry on research.

It follows that most of us very much need to have a place to have scientific facts revealed. Not only is this true in the smaller manufacturing industries, but it is even more vital for the public to have these independent public laboratories of research which the colleges and universities can so well maintain. It really is not so much the amount of work done that matters, as it is the unbiased check that such laboratories can give upon the results that are revealed and published by the larger corporations.

We do not charge that the large corporations color what they print about their laboratory results, but it is human and almost inevitable that they show the best side of what they find out, and somewhat neglect the unfavorable aspects of those things they are trying to promote.

By doing a very little work sometimes with small funds, the smaller college laboratories can aid industry and the social body a great deal. The exact amount of money at their disposal is not of prime importance although it is true that they need a vastly greater support than they now have.

The professor who has one thousand dollars a year to spend for all his equipment, including its repair, and maintenance, is so handicapped that he can surely do but little with the energy that he puts into the work.

I should endorse what Professor Magnusson said: Industrial establishments of any size that do no research have "signed up for the exit." However, industrial research in smaller establishments may not be carried on because they have not the facilities, and thus they have to depend upon the colleges.

I find much in Professor Sorensen's paper which is of interest. Professor Sorensen starts out with an assumption which surely needs no argument,—that research and engineering are inseparable. Research *must be* a part of engineering education. He takes the same attitude as Professor Magnusson does in pointing out the necessity for it from the standpoint of education. This is self-evident indeed.

Professor Sorensen gives the time honored definition of engineering that I believe was given by Tredgold, the first President of the Institution of Civil Engineers in England; "The art of directing the great sources of power and nature for the use and convenience of man," etc., running through many, many words. It starts as a catalogue of the functions of engineers and thus its weakness is obvious. It can, of course, only begin to catalogue the functions of engineers, but I think that in this very definition, a part of the weakness of modern engineering education lies. Educators and engineers have been more or less hypnotized by such definitions of engineering, emphasis being placed entirely upon the technical aspect of engineering, the scientific, and the big and glorious things to be done by engineers.

I should substitute a very much shorter definition for engineering. I define an engineer as one who directs the economic use of matter or energy. I should let it go at that because I believe that we have among us as great engineers who are directing the destinies of banks or steamship companies, from the standpoint of executive officers, as we have in any other capacity. In other words, technique should not be stressed exclusively in the work that is done in the colleges. There should be a little more emphasis placed on economics. There are very few colleges today that devote any great amount of time to the study of engineering economics. I do not see how it is possible to turn out men with a proper attitude toward

1. A. I. E. E. JOURNAL, November, 1925, p. 1243.
2. A. I. E. E. JOURNAL, December, 1925, p. 1288.
3. A. I. E. E. JOURNAL November, 1925, p. 1208.

engineering without giving them much study of the principles of engineering economics; not the old social economics, but the engineering student does need a very considerable amount of engineering economics if he ever becomes a true engineer.

I wonder how much deleterious effect this long-drawn-out definition of Tredgold's has had upon engineering education. Has it not hypnotized the profession somewhat into thinking too much about the imparting of information about technical things; perhaps information about the things that can best be learned by the man after he is out of college?

In Professor Sorensen's paper I found one thing with which I think many men in practical research would particularly take issue. That is the standpoint that the undergraduates thesis was wisely eliminated. Professor Sorensen says "it was therefore wisely eliminated." The very next sentence takes the curse off, "But we should not forget that the thesis is symbolical of research—a function which must be the keystone of engineering education if the engineer is to occupy the place for which he is ambitious."

I think that is certainly true. The thesis is needed to support the idea of research, to give some little practise in the methods of research, with the object of bringing out latent research talent in the student.

Professor Sorensen reveals that he has some such idea in a latter part of his paper, since he speaks of the honor sections that are established at Pasadena where the better men are permitted some chance to help in advanced and special work, assisting research men. I think he has there revealed his true attitude toward the research that may be done by undergraduates.

It seems to me that the practise of segregating the students into the ordinary and the extraordinary,—the latter class including these so-called honor men,—is one of the very best developments I have ever seen. I wonder if the real reason for eliminating the undergraduate thesis was not rather the difficulties that were encountered in lack of equipment or lack of time and energy for the administration of the theses than the lack of educational and developmental value in them?

In the paper by Dean Pender and the one by Professor Sorensen there are two quite distinct methods given for the selection of engineering student material. Of the two, I think the one that is the more hopeful is the one that is being tried out in Pennsylvania. The statement that Harold Pender made is quite true; that a boy fresh from high school is usually just a boy,—and I think it does require the few years of college which are a part of the Pennsylvania plan to bring out the judgment of a student and too, to weed out the defective material found among students. It is not defective material except that it is unfit for engineering although possibly very fit for some other, perhaps higher, walk of life. At any rate, there is a great difference among students in their fitness for engineering.

I am somewhat in doubt as to the real value of the physical examination in the Pasadena plan because we have in our electrical history so many able men who might have had difficulty in passing the Pasadena physical test. Is it not going to eliminate an occasional man who has great latent ability in analytical ways?

H. V. Carpenter: This matter of engineering education is one that we shall always talk about I suppose. The Society for the Promotion of Engineering Education is at the present time spending something like a hundred thousand dollars, and I don't know how many dollars' worth of time, in analyzing methods of engineering teaching.

It seems to me that one of the most difficult problems we have before us in that study is this matter of research. You remember that some Roman ruler said, "All right, if we destroy the Greek statuary, we shall send some men out and have it replaced." If we aren't careful, we shall put our research work on that same mechanical basis. I believe that a research man is born. Maybe Dean Magnusson can make a research man, but I am afraid I cannot. I think it is more a matter with us of being able to discover the research man when he comes along in our classes, rather than being able to take an entire class of students and turning them all into first-class research thinkers.

What we need to do is to teach these men to think, and research is only one of the better methods of teaching a man to think. A large share of these boys will never be research thinkers, but they will be very effective engineering thinkers in the ordinary sense of being able to go out and size up a job and put through the best design for it. They may not be research men, but they will be thoroughly useful men on straight engineering propositions.

It is our business to give the man who can do original thinking the inspiration to go ahead to develop his abilities in that line, and to give him a chance in the laboratory. Professor Sorensen's scheme is a very good one; they have adopted a similar one at the Massachusetts Institute of Technology where the honor men are to be given a chance to do as much as they please. The smaller institutions have always done that to a considerable degree in an easier way, having a much simpler problem.

Dropping the thesis was a good thing, I think. I agree with Professor Sorensen on that as a requirement for every student, but for the student who shows interest, I think the thesis should be maintained, and carefully nursed along. We cannot expect revolutionary things from the senior, but perhaps if we start a real genius to thinking he may turn out a revolutionary piece of work in later years.

L. J. Corbett: Doctor Magnussen describes the tendency to take research away from the colleges. I think we need not fear for that, as times are changing. As he states, the large companies are doing a great deal of research, but there is another factor; they also need men—and one of the ways to develop men is through this very research work. I believe this is being recognized by some of our large companies, as evidenced by the assistance which has been given recently, to both the California Institute of Technology and Leland Stanford, Jr., University, in the way of aid in the establishment of high-voltage laboratories. These, no doubt, will give a good account of themselves in contributions to engineering research, and some students will recivee valuable training in this field.

From Mr. Sorensen's paper I note that they are omitting the engineering thesis at the institution he represents. However, from the discussion which took place, I see that there is still some opportunity given for the honor men to investigate along the lines of their special inclinations, thus recognizing work on such theses.

To return to Doctor Magnusson's paper, we must recognize the tendency of the companies of today to require specialization in their men. This, I think, has been the inference in the advice which has often been given to engineering colleges to have actual departments of research where some men of the staff could go ahead and do research only, without the change in mental attitude which is necessary when a man does some research and also teaches a group of undergraduates, old, well-known material.

I think the work of the teacher, as Professor Carpenter has stated, is inspirational. I think that if you can inspire a student to make the best use of his faculties, and not to consider his education complete when he has his degree, but to go ahead with his studies and research—you will do a greater work than merely filling him with information and making an encyclopedia of him. I think this quality is particularly exemplified in the man we have with us in the person of Professor Ryan. I believe that all his students will vouch for the inspirational quality of his work.

There is one feature in Dr. Pender's paper that struck a discordant note. In one of his conclusions there is the statement that the student should recognize that engineering is a profession, and not a job. That is all very well for us to recognize, but I think we should not emphasize it too strongly to the under-

graduate student, because it is due to such thoughts that we have men who are reluctant to don overalls after getting their degrees. I think a man would get farther in the engineering profession if he were willing to don overalls for a time after his graduation and learn the rudiments of practical work.

J. S. Bates: I once heard an engineer defined as a man who is skilled in the use of the word "approximately." There is really a great deal in that because no matter to how many decimal places we carry our calculations, there is always one more; one or a vast multitude makes no difference. For that reason we should say a very important part of an engineer's education is to determine what percentage of error is to be allowed.

G. S. Smith: In the University of Washington we still have the thesis work scheduled as an elective but it has been virtually discarded, since it is seldom chosen by the student. However, I believe we have found other ways more effective in obtaining the results aimed for in the usual thesis work.

Several of our courses scheduled for upper classmen and graduates, are presented in such a manner that each student, or more often a group of two or three students, selects or is assigned some individual problem to be worked out completely. These prob ems are usually of such a nature that they require a considerable amount of thought, reference work, or experimental work, and thus arouse in the student any latent inclinations toward research work.

As an example I should like to mention a course to which we have paid a good deal of attention in our institution; that of electrical transients as a prescribed course of undergraduate study. In the laboratory part of this course a certain number of topics are assigned to the student for which he must obtain representative oscillograms. This is the more or less routine or practise part of the course. To satisfy the remainder of the requirements, the student must select some problem or topic, acceptable to the instructor, to be investigated by the taking of oscillograms. This problem must be one which has not been previously chosen by other students who have taken the course. Thus their work is, to a certain extent, original.

The response on the students' part is usually more than gratifying. They not only put more energy and thought into this part of the work than in the routine portion, but they also show a strong tendency to attack it from the investigational point of view; that is, they try to find the best method of attack, try to determine the results they expect and then attempt to verify them experimentally, watching all the while for unexpected results. At times, of course, they make complete failures, but more often they are very successful.

H. H. Henline (communicated after adjournment): I wish to emphasize the importance of full and frank discussion of the problems of engineering education by members of engineering faculties as well as by executives in industry. These authors have pointed out some very serious defects which are found in many curriculums.

Most of the engineering curriculums now in effect were planned twenty or more years ago, and changes made since have not altered in any essential details the general plans followed originally. Therefore, we find that most of the curriculums furnish excellent preparation for certain types of work which some of the graduates enter. However, this number seems small when compared with the total. On account of the extremely rapid progress which has been made in many branches of engineering during the past few years, we find ourselves living in a period when the applications of engineering knowledge are so many and diversified in character that any curriculum designed to meet directly certain needs in industry may indeed prepare men in a most excellent manner for those needs, but it fails utterly to prepare them for the great range of engineering problems, both executive and technical, which all graduates will be called upon to solve.

There is a strong and growing tendency to choose executives from the men with engineering training, since the problems which executives in industry must meet are becoming so complex and so closely allied with fundamentals of engineering that great dependence must be placed on the judgment of engineers in order to reach the correct solution. Obviously the schools cannot train men directly for executive positions, since qualifications for such positions depend greatly upon inherent characteristics, and any amount of training would not make capable executives of men who do not possess the necessary characteristics. However, if we wish the engineering graduates who do possess such characteristics to have opportunity to enter the management side of engineering, we must give them the broad, general foundation so absolutely essential.

One of the most noticeable features in the large amount of discussion of curriculums occurring in recent years is the fact that many of our largest employers of technical graduates now wish to secure men who have had a broad training in general subjects and the fundamentals of engineering rather than men who have specialized in a particular branch of engineering. Thus we find that the old situation in which teachers wanted to adhere to fundamentals, and many executives in industry advocated certain specialized courses, is rapidly reversing. Now we find the leaders in industry not only frowning upon specialized courses, but even considering many courses as too highly specialized which are given with the excuse that they are necessary from the standpoint of fundamentals.

In the planning of an engineering curriculum, certain decisions must be made as to the types of activity for which it should prepare men. In the present stage of development it seems necessary to recognize the needs of two distinct groups of students. Those who expect to spend their lives in highly technical design or research must have a more extended technical preparation than those who will be engaged in commercial or industrial phases of engineering. Both groups need a broad foundation on such subjects as English, economics, biology, geology, history, business law, etc., and a thorough training in chemistry, physics, mathematics, mechanics and other subjects which make up the heart of engineering. Such training should be mixed with, and followed by courses giving the fundamentals of all of the principal branches of engineering, and there should be a reasonable amount of time available for elective subjects. Thus far there is no serious difference between the wishes of executives in industry and teachers of engineering. It, therefore, seems that the chief cause of argument is the relatively small group of men who will engage in research and other highly technical phases of engineering. This group must have better opportunities for the development of research ability and specialized study than can be provided in any four-year course which makes necessary the provisions for training in the fundamentals.

It seems that the best solution of the problem may be a four-year course following the general outline mentioned above and leading to some such degree as Bachelor of Arts or Bachelor of Science in Engineering. This curriculum should be so planned that students may have good opportunity to develop powers of initiative and judgment to the maximum extent, and to determine the kind of intellectual effort for which they are best qualified. In order that they may see how they can best fit into that field, it should give them a broad outlook and an excellent perspective of the whole engineering field. Graduates of such a curriculum would be prepared for commercial pursuits and for many types of technical work in which employers prefer that specialization be deferred until after the entry into industry. It is believed that they would advance more rapidly in either commercial or technical employment than if they had graduated from the narrower four year engineering curriculum.

For those who wish to prepare for research and other highly technical branches of engineering, there should be provided opportunities for two years of graduate study. Having completed the liberal four-year curriculum, they would have the

broad foundation which should precede advanced study. The graduate curriculum should be planned with the idea of developing ability in research and permitting specialization in analytical studies, design, or other branches of engineering. Since the number of students in the graduate classes would be relatively small, the effectiveness of the training would be maximum. The progress would be much better than could possibly be made in the same work with undergraduate classes containing many students not really qualified for or genuinely interested in such subjects.

I believe this combination of four years liberal curriculum for all and two year graduate curriculum, for those who are properly endowed for and desire it, would result in producing men better qualified to take their proper places in the world than are those who complete most of the present-day curriculum.

All engineering students should realize that it is impossible to escape passing through an apprenticeship period of some sort. A university curriculum cannot possibly replace the apprenticeship period except in the cases of the comparatively small number of persons who are preparing for research and highly technical progress. Therefore, it is extremely important that the curriculum be such as will aid in choosing the proper kind of apprenticeship to fit the individual's mental endowment and his aptitudes. There should be fewer misfits because the first four years' training would give them an excellent foundation, and they could choose the type of work most interesting to them. This would eliminate a very real difficulty now in common existence. For instance, a boy before graduating from high school has built radio sets, worked in a local power plant, or had some kind of electrical experience. Perhaps electricity appeals to him more strongly than any other subject. He wants a university education because he has been told that it will enable him to earn a good salary immediately after graduation, and will go far toward insuring success in later life. What then is more natural than for him to register in electrical engineering, because here is the opportunity, in his opinion, to secure the university education he wishes and at the same time specialize in his favorite subject. Naturally he has considerable pride in his choice and is reluctant to make any change even though the first year or two may prove that he does not possess the necessary types of ability to succeed in engineering. He may eventually graduate and begin work, still determined to be a successful electrical engineer. The result is in many cases an employe who has not the ability and characteristics necessary for his work. He must then work on as best he can and be a failure or only a mediocre success in electrical engineering, or find something to which he is better adapted. In so far as possible, a young man's interests and abilities should be determined before he graduates. If this can be fairly well accomplished and he can be sent out either with the broad four-year training, or better, with both it and the two-year graduate study, his chances of success should be greatly improved, and he should be a happier man in later life.

R. W. Sorensen: I would like to add to the list of books given at the end of Professor Ryan's paper one entitled, "Ions Electrons, and Ionization Radiations" by J. H. Crowther, published by Edward Arnold, London. That book is easy to read and it presents in a reliable manner much of the information about ions that engineers wish to know.

In the three papers bearing directly upon education, you will, of course, find differences of opinion, and so there should be. The biggest crime educators could be guilty of would be that of making a standard curriculum, which would be the same for all engineering colleges. In fact, we often remind ourselves at California Institute of Technology that we must not simply add to the group of good engineering courses in California just another course like the one at our State University or like Professor Ryan has developed at Leland Stanford. We at the Institute are spending annually about $700 per year per student enrolled, to carry on our work. That money has been given us by individuals for a specific purpose and should not be used to duplicate the work of other institutions.

Dr. Magnusson has sounded a keynote when he says every faculty man should do enough research work to show that he has the ability to inspire students in that direction. Some undergraduates are qualified to do research work along with their regular undergraduate work. Such men should be given an opportunity to do that work. Also, there should be graduate students, the more the better, doing research work, and the college should make such provisions for such a plan. In this way, every student has a chance to come in contact with research work, learn what it is and methods of procedure. Every engineer will, to a large extent, have his success determined by the amount of research enthusiasm which he can develop, even though that enthusiasm is not applied to the type of problem ordinarily classified as a research problem.

As to the senior thesis for all, the discontinuance of that plan was due to several factors; one being lack of time on the part of faculty to supervise many students and assign each student a problem of just the proper magnitude to fulfill the requirements for graduation. In place of the thesis, certain problems are assigned students, the problems selected being tempered by the circumstances under which the student is working. Such a problem does not have to be written in thesis form, thus allowing all the available time for work on the problem.

Why do we include four years of English in our curriculum? We have had complaints that the engineers are underpaid, and underpaid chiefly for one reason; that the engineer confines most of his contact with men to those who talk only engineering language, and there is no use to try to sell engineering information to other engineers unless you are a much better engineer than the other man, which doesn't happen very often. On the other hand, there are thousands of people in the world who want engineering information and who would take it if presented to them so they could understand it. You can't present engineering data to the artist in a way that he will understand it unless you know his language; you can't present it to the doctor, lawyer, or merchant in a way that they can understand, unless you know something of their language.

Therefore, we have a department of English which runs through five years of our five-year course, and we must have a large department in order to keep the type of instructors we have, instructors whose business it is to inspire men and cause them to make of themselves all-round men. That is the reason we think it worth while to put in a five-year humanity course right along with a five-year technical course. Many of us would not do the things we do if some seemingly insignificant thing had not inspired us to go in an inviting direction. Without the instruction we would have failed in finding the doorway to new and interesting fields of endeavor.

In reply to the comments made by Messrs. Robinson, Clark, Henline and others, there are many details about which we could argue, but each exception only makes plainer the fact that all individuals should not be required to follow the same course of preparation for engineering work. Some men should prepare a thesis, some should not, some should have five years of education in the field of English literature, including some history and economics, others should find it more profitable to plan a different use of their time, but in nearly every case, I would conclude that in the essential things there are no differences of opinion—except as to relative values. This condition could not be otherwise because engineers differ as to details even in designing machines, when a much smaller number of variables are encountered than is the case when we attempt to form the character of the youth who will in the future be our engineers.

Reference to values in character building prompts me to direct attention to the value of the training obtained on the athletic field as evidenced by the success of many of our engineering students who participate in athletics. A survey of the condition

governing athletics at many of our educational institutions indicates to me that the advantages of athletics are for the most part lost to engineers because training for athletics has become such a time-absorbing specialty as to make it almost impossible for an engineering student to be on his college team. Our educators in the technical field, and those who are our friends, should help correct this condition of affairs.

C. E. Magnusson: Mr. Robinson's remarks lead me to think that I failed to state clearly what I had in mind. I meant to say that education is essentially training to think; that engineering education is training to think along engineering lines; that the main purpose of engineering students during their four years in college should be to gain clear concepts of the basic physical laws underlying engineering and acquire the ability to apply these laws to the solution of quantitative practical problems. The rest of their college work is accessory to this backbone of engineering education and may vary widely for different individuals. It goes without saying that all live engineering colleges frequently revise their curricula. At the University of Washington, the revision of curricula in the college of engineering comes regularly on the calendar every four years, and many changes both in regard to required courses and their content have been made during the past twenty years. I am grateful to Mr. Clark for emphasizing the value to industrial establishments of research in our engineering colleges although this phase of the problem does not come under the title of my paper.

FUNDAMENTAL CONSIDERATIONS OF POWER LIMITS OF TRANSMISSION SYSTEMS[1]

(Doherty and Dewey)

AND

ANALYTICAL DISCUSSION OF SOME FACTORS ENTERING INTO THE PROBLEM OF TRANSMISSION STABILITY[2]

(Fortescue)

Seattle, Washington, September 16, 1925

P. H. Thomas: The paper by Doherty and Dewey emphasizes even more than those of previous date the part played by the terminal apparatus in stability of operation. Of course, it matters not what the electrical equations show as to the theoretical capacity of a long line if when terminal apparatus be applied to supply power and receive load the combination is unstable to operate, as might easily be the case with loads anywhere nearly approaching the theoretical capacity of the line should the usual present designs of synchronous apparatus be used.

However, we have this fact to remember; the capacity of the line as shown by equations is an absolute limit without power of change until some of the physical constants of the line are changed, while the limitations of the terminal apparatus are merely matters of economy and cost. The very long transmission line may well represent $125 per kilowatt of delivered power, while the terminal apparatus costs much less; at least so far as the securing of suitable stability characteristics is concerned. If the choice lies between limiting the maximum duty of the long line and adding to the terminal-apparatus cost, the latter course is to be chosen, generally speaking.

The proposal to correct by simultaneous and automatic support of the field magnetizing turns the falling field strength when a line is suddenly overloaded, is a significant and important proposal and the analysis offered is clear and to the point. No doubt there are other ways of accomplishing this same result.

The 28 per cent greater load carried by the rectifier-excitation test as reported over the regulator test in the experimental line, is very encouraging. At the critical point of the regulator test it is evident that a further increase in power transmitted would require a higher actual field magnetism both on account of the higher load and on account of the less favorable power factor that the line will demand and temporarily also greater on account of the initial drop in terminal voltage. It should be noted that the motor end must drop behind on the increased load before anything at all happens in the electrical circuit. But this regulator cannot act until the voltage actually has dropped and by that time the system has dropped out of step and the regulator never gets a chance to try. With the rectifier, however, an excess of exciting power is added in the field before the motor drops back to the new position for the greater load and the field is ready to support the necessary additional power current.

I think the authors are a little too severe in their reflections on the line charging current. While it may be true that with certain set-ups due to the limitations in machines, the total theoretical maximum power which can be delivered by the line will be slightly less over the line having its normal electrostatic capacity than over a hypothetical line with no capacity, nevertheless it is not likely that charging current will be a detriment under practical operating conditions.

The statement that a certain 300,000-kv-a. station may deliver more power over two lines than over three and none at all over nine lines is not so significant as it might seem. It simply means that, for the three or nine lines, the system is so proportioned that machine capacity which should be devoted to carrying kilowatts is absorbed in carrying charging current or that the ratio of synchronous condensers to number of lines is not favorable. Either the kv-a. of the station should be increased by building the machines to operate at a lower power factor or shunt reactance or other means used to neutralize a part of the charging current. It goes without saying that it would not be economical to use an unnecessary number of lines.

With regard to the authors' Fig. 3 and the discussion of the part played by field current, I should like to point out that, with a heavily loaded line, there is very little choice as to power factor, for this is definitely fixed by the load and the terminal voltages and will inevitably be high at the generator end. However, there is this advantage of power factor near unity; the effect of added lagging current due to increase of load on the drop from internal impedance within the machine is small with high power factor. This is an important matter.

Since the power factor changes with every change in load on the long line, the curves of Fig. 3 should be supplemented by other curves showing the effect of such change of power factor, and these modified curves might easily show a different best relation between low-power-factor and high-power-factor loading, from that indicated by the uncorrected curves.

One other point; the authors state that the scheme of using divided line conductors to reduce reactance and increase capacity has not found favor partly because of the increased charging current. As I see it, this increased charging current is, on the whole, no disadvantage, for on any useful loading it greatly improves the line power factor. While it is true that leading current will tend to reduce the field-current setting in generators, this is a matter affecting only the performance of the generator, subject to correction in a number of ways. If the rectifier excitation scheme proposed in the paper or any equivalent scheme is available, this objection to the high charging current disappears. Meanwhile the reduction of line reactance which accompanies the increase in capacity with divided conductors, means an increase of substantially the same proportion in the maximum load the line will carry, assuming the percentage of line resistance loss to be kept constant. With a 20 per cent increase in line capacity in a 350-mi. line and with a favorable line power factor, any generator difficulties from the additional charging current would no doubt be cared for in the same suitable way. As a matter of fact on any full loading no charging current would appear at the terminals as the reactance energy of the line would absorb it.

1. A. I. E. E. Journal, October, 1925, p. 1045
2. A. I. E. E. Journal, September, 1925, p. 951.

F. L. Lawton: In the paper by Messrs. Doherty and Dewey, considerable emphasis has been given the question of voltage regulation of the synchronous equipment of transmission systems. This, however, is in line with the papers[3] and discussions[4] at the last Midwinter Convention when the subject of high-speed excitation was given prominence.

As the method of regulation outlined by Messrs. Doherty and Dewey—viz., the use of mercury-arc rectifiers as adjuncts in the excitation circuits of transmission-system synchronous equipment—is probably the most promising development looking toward increased system stability, it seems wise to discuss it somewhat in detail.

During the course of various investigations of the stability of power-transmission systems, it was realized that considerably greater stiffness in a system would be desirable; also, that such greater stiffness could be secured by the use of excitation systems having a time constant much smaller than usual. As a consequence, Messrs. Fortescue and Wagner discussed results they had obtained with a so-called high-speed exciter, at the 1925 Midwinter Convention.[5]

While it is true that less voltage fluctuation will occur during load or short-circuit transients, when the synchronous machines of a power system are excited by high-speed exciters, it must be remembered that such exciters are inherently not different from any other exciter, so far as behavior under transient conditions is concerned. That is, when lagging load is suddenly added to a generator so equipped, the terminal voltage drops. The decrease in voltage energizes the Tirrill-regulator relay which short circuits the exciter field resistance, permitting the generator field current to increase.

After an appreciable time, the alternator terminal voltage is restored to the normal value. *Inasmuch as the alternator armature reaction is not compensated for at the time it occurs, the power limit*, for slowly applied loads, of any system equipped with high-speed excitation equipment, *is no greater* than for a system provided with normal exciters. Furthermore, as it is now realized that a power-transmission system is inherently stable for any load up to the steady-state power limit, no matter how added, there is of comparatively little advantage in the use of such high-speed exciters beyond the reduction of voltage fluctuations.

Let us consider the case of an alternator equipped with an ordinary excitation system with the addition of a mercury-arc rectifier, excited from the line, as an adjunct. When a lagging load is thrown on such an alternator, the rectifier supplies an excitation current proportionate to the line current, varying simultaneously with it. *As a result of the simultaneity of action, the alternator armature reaction is at all times counterbalanced by a proportionate field current.* That is, *the armature reaction is effectively neutralized.*

As Messrs. Doherty and Dewey have indicated, a reduction of about 50 per cent in effective armature reaction was obtained. While this reduction was not so great as theoretically possible, nevertheless it resulted in an increase of 28 per cent in the steady-state power limit of a 250-mi. miniature system.

It is worthy of note that this gain was maintained during tests involving the sudden addition of loads when if ever, it might be expected that the rectifiers would be ineffective. Not only were increased power limits obtained, but practically no decrease in voltage occurred when a large load was suddenly added to a system equipped with mercury-arc rectifiers; but as much as a 20 per cent momentary drop in voltage occurred when the same load was added in the same way to the system using normal Tirrill-controlled excitation systems.

The advantages of rectifiers as adjuncts in the excitation circuits of transmission-system synchronous equipment are probably most marked in the case of system short circuits. Tests similar in all respects except the excitation circuits, have been made on the systems illustrated by the accompanying Fig. 1 to determine the maximum amount of power which could be transmitted with stable operation under the condition of a half-second, single-phase, dead, line-to-line short circuit at the mid-point. It has been found that the system with rectifiers

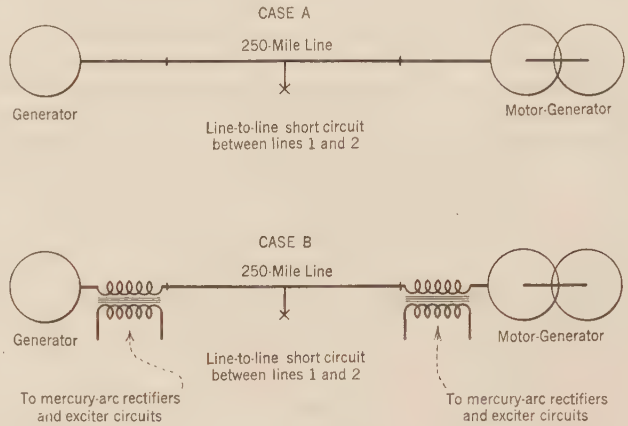


Fig. 1—Schematic Diagram of Systems used for Short Circuit Tests

could carry 50 per cent greater load with much less fluctuation in voltage. To illustrate the comparative voltage fluctuations, Fig. 2 herewith has been prepared. Case A, Fig. 2, shows the three receiving-end voltages for the system of Case A, Fig. 1, while Case B gives the corresponding voltages for the other system. While the duration of short circuit for Case B was somewhat less than for Case A, the load being carried prior to the short circuit was 35 per cent greater and the initial short-circuit current 50 per cent greater. In spite of these unfavorable factors, the decrease in voltage was less with the system of Case B; virtually no over-voltage occurred when the short circuit was cleared. With the system of Case A, considerable excess voltage occurred some time after the clearance of the short circuit; a much greater time was required for the restoration of normal voltage.

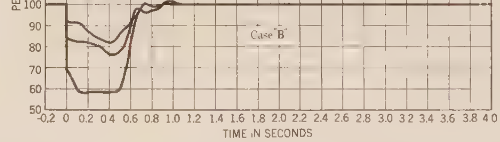


Fig. 2—Voltage Disturbance During a Single-Phase, Line-to-Line Short Circuit on a 220-Mile System

The above facts illustrate the very important advantages which may be gained by the successful application of mercury-arc rectifiers in the excitation circuits of the generators and other large synchronous equipment of power-transmission systems. There appear to be no disadvantages beyond the possible necessity for oil circuit breakers of a somewhat higher rating, at a few points.

3. Power System Transients. V. Bush & R. D. Booth, A. I. E. E. Journal, March 1925, p. 229.
4. Discussion, A. I. E. E. Journal, July, 1925, pp. 766-771.
5. A. I. E. E. Journal, pp. 767-770.

In conclusion, it appears that the only high-speed excitation system which will enable the securing of increased system power limits, for all conditions of operation, must be such that the armature reaction of the synchronous machines is effectively neutralized by the addition of field ampere-turns in the proper space-phase simultaneously with the occurrence of the armature reaction.

I believe the mercury-arc rectifier, properly applied as an auxiliary in the excitation circuits of synchronous units, is the first development giving promise of *a real increase in the power-transmitting capacity of transmission systems.*

S. B. Griscom: The statement by Messrs. Doherty and Dewey that, during transients, "the synchronous apparatus becomes inherently more powerful" is not clear. The field transient accompanying an increase in armature current is of such a nature as to tend to prevent the main field flux from decreasing, but it does not strengthen it. Actually, the magnetic flux starts to decrease immediately upon an increase in armature current, and consequently the field becomes weaker. Another way of stating it is that the very presence of the additional field current, flowing through the field resistance, is *due* to a decreasing field flux.

Under "Regulation," it is stated that the slope $\frac{d\,E}{d\,P}$ of the voltage-power curve determines the degree of stability. I should like to point out that such a criterion does not take into consideration the mechanical transients which are always coincident with an unstable condition, and it may, therefore, lead to erroneous conclusions. In the region where $\frac{d\,E}{d\,P}$ approaches infinity, $\frac{d\,P}{d\,t}$ approaches zero, because $\frac{d\,P}{d\,\theta}$ is limited by the mass of the synchronous machines. For this reason $\frac{d\,E}{d\,t}$ becomes very small and, in the case of large systems having heavy masses, is undoubtedly much less than the combined time constants of voltage regulators, exciters and generator fields, for a normal building up of load. The maximum load which may be carried under steady conditions is therefore considerably increased by the use of voltage regulators. This conclusion agrees in a general way with similar conclusions by the authors although in some cases apparently contradictory statements and data are introduced.

In particular, it would be expected that the tests reported at the bottom of the eleventh page should show nearly equal maximum loads for the two forms of excitation used, provided the load was built up by increments that were small as compared with the stored energy released during a small shift in phase of the synchronous motor. It is also probable that a load consisting of a large number of small synchronous units would cause the power transmitted over the line to change more slowly, giving more time for the regulator to function.

In a similar manner, voltage regulators on synchronous condensers located at intermediate points on a transmission line, by holding the voltage constant under a gradually increasing load, should permit a much greater power to be transmitted than the same line with the same total condenser capacity located at the receiver end only. The maximum power limit of such a system, as given by the authors appears to be entirely too low for a condition of steady loading. During transients, the maximum load that can be transmitted safely is considerably reduced but will still be much higher than a straight-away line for the same disturbance.

The use of synchronous condensers at intermediate points has been discussed a number of times, but the advantages apparently have not been fully appreciated. Condensers are usually installed for the purpose of voltage regulation and since the receiving end of the line is usually the only point where voltage regulation is needed, all of the condensers are located there. However, the real function of the condensers is to supply the reactive energy loss due to the flow of current through the line reactance. This loss is distributed practically uniformly over the length of the line and consequently a reduction in copper loss and a slight decrease in total condenser capacity may be effected by installing a portion of the condenser capacity at an intermediate point. Such an arrangement would tend to reduce short-circuit currents, particularly at the receiving end which is usually a point of high power concentration. Location of condensers at intermediate points should not prove unduly expensive or difficult because, in the majority of cases, switching stations and attendance will be required for line sectionalizing. Machines of suitable characteristics and equipped with a high-speed excitation system, or compensation, are of particular advantage for this application. It should be noted, however, that such features are made desirable principally by the conditions obtaining during transients and not for steady loading.

R. D. Evans: Probably the most interesting data submitted by Doherty and Dewey are the results of the calculations shown in Fig. 2 of their paper. This figure shows the "Maximum power which can be transmitted 250 mi. at 220,000 volts, shown as a function of the capacity of synchronous apparatus, and the number of transmission circuits."

The curves of Fig. 2 were presented for the purpose of showing the importance of the charging kv-a. of lines in reducing the power limit and they serve this purpose in an excellent manner. However, the important effects of the charging kv-a. in limiting the maximum power appear only when the synchronous capacity is small in comparison with charging kv-a. of the transmission line. This condition of operation would suggest that a lower transmission voltage would give higher actual power limits.

The condition in which the generating capacity is small per line is of relatively minor importance because the power to be transmitted per circuit at 220 kv., 250 mi., must be of the order of 75,000 to 125,000 kw. in order to be within the economical range at the present time. With this relation in mind, it is advantageous to compare the results shown in Fig. 2 for different kv-a. capacities of synchronous apparatus. In the first place, it will be noted that the characteristics of machines assumed by Doherty and Dewey are such that the rating of the machine cannot be developed because the power limit of the system is approximately two-thirds of the nominal capacity of the synchronous machines, that is, 100,000-kv-a. capacity on this line will show a power limit of approximately 70,000 kw. per circuit. If the characteristics of the terminal equipment are altered so that the reactance is approximately two-thirds, and the field current approximately three-halves of the values assumed, the power limit would be increased to approximately 100,000 kw. This condition would correspond to the curve given in the paper for 150,000 kv-a. in synchronous apparatus. Similarly, if a power limit of 150,000 kw. were to be obtained, the machines should have approximately somewhat less than two-thirds the reactance and more than three-halves of the excitation of the machines assumed by Doherty and Dewey. In other words, the power limit per circuit can be increased up to at least 125,000 kw. per circuit by the use of machines of suitable characteristics. The significance of this discussion is that the desired static limit may be obtained by merely modifying the authors' assumptions so as to employ machines of lower reactance and higher excitation. In the absence of alternatives, which are still in the development stages such as special regulator and compensator schemes, the use of machines of suitable characteristics is a practical solution available at the present time for producing quite marked increases in the stability of systems.

In view of the position taken by the authors, that static

limits are the only limits that are worthy of computation, it is interesting to compare the calculated static stability limits as given in Fig. 2 of the paper with the practical results of experience on an actual 220-kv. system. For a single-circuit, 250-mi. transmission system operated at 60 cycles, with approximately 200,000 kv-a. in synchronous apparatus at each end, the static limit is calculated to be about 115,000 kw. In the June issue of the *Electric Journal*, H. A. Barre states that the static limit of the Edison System was reached under a particular emergency condition. For this condition, power was transmitted from 240 to 270 mi. over a single circuit at 220 kv., 50 cycles, with approximately 200,000 kv-a. in synchronous apparatus at each end, and the static limit was found under actual operating conditions to be 183,000 kw. One would expect that the static condition on the Edison system would correspond well with the other condition mentioned previously, the greater length of the 50-cycle system and the probably greater transformer impedance roughly compensating for the increased frequency upon which the calculations were based if the authors had assumed machine characteristics corresponding to those of the synchronous apparatus on the Big Creek system. What is the explanation of this discrepancy from 183,000 kw. on an actual system to 115,000 kw. as given in the calculated results? In the first place, the exact assumptions used by Doherty and Dewey are not stated, and it may be that the explanation lies in them. If such is the case, the Fig. 2 should be interpreted with care. A possible explanation may lie in the fact that probably synchronous motor load was assumed in the Doherty and Dewey calculations, whereas the actual system involves a certain amount of resistance load which would cause the power to fall off with drop in voltage. The influence of the load characteristics is not mentioned, so far as the writer can recall, at any point in the paper, and it may be that this factor is of importance in the particular case of the static limit on the Edison system and under certain conditions would undoubtedly be of great importance in other cases. The explanation of the discrepancy between the calculated maximum limit and the maximum limit obtained under actual operating conditions is, of course, very important. It is worth pointing out that actual static limits may be appreciably in excess of calculated limits which do not take into account all the factors affecting stability.

S. W. Copley: These two papers indicate that the methods of calculation used do not differ greatly fundamentally, but there is some difference between them in the assumptions made as to the values used for the characteristics of the terminal apparatus. This difference causes some important divergence in views as to the power-limit figures. Possibly Doherty and Dewey are too pessimistic in their assumptions with respect to the reactance of terminal apparatus, or they have not given enough credit to the action of voltage regulators in holding the system together. Both of these points warrant further investigation. Machines of lower reactance can be designed and a regulator which has higher speed characteristics is a possibility. There are certain drawbacks to the application of such machines and regulators, but if the limits of power transmission must be raised the disadvantages can without doubt be overcome.

C. L. Fortescue: Messrs. Doherty and Dewey have presented with clarity the characteristics of synchronous apparatus which are of importance in the problem of stability. In dealing with the stability of machines of this type, they have laid much stress on the fact that high power factor is detrimental to stability, as it involves low excitation or, what is the same thing, low internal voltage. While undoubtedly at times, transmission lines reach very low loads in which the excitation is correspondingly low, I do not know of a single case in which a system was thrown out of step by a sudden increase of load or a short circuit due to low excitation. I believe that the explanation which I shall give later will account for the fact that instability under such conditions is practically unknown.

While I believe we should keep such cases in mind as elements of the problem, I feel that the authors have over-emphasized their importance and may, therefore, produce a false impression in the minds of those who are not sufficiently familiar with the problem. A properly designed transmission system will make provision for the generators not to supply all of the charging current at light load, and, at heavy loads, the generator power factor will be normally lagging. Two transmission lines properly designed with the proper size of generating station and with proper provision at the receiver end and intermediate points to take care of the line reactive-volt-ampere requirements will always transmit more power than one line. I state this fact not because I believe the authors intended to convey the opposite impression but the emphasis they lay on certain features of generators and synchronous motors might easily convey the opposite idea to the minds of those who are not closely in touch with the problem.

I had felt encouraged when I read the statement made by the authors on the fourth page, column one, and in the first part of column two as to the importance of excitation, though I will take issue with them in regard to part of the statement by referring to a discussion on excitation in last Midwinter Convention by several of my colleagues in which the possibilities of high-speed excitation were discussed at some length and with considerable emphasis. Later on in their paper I was disappointed to find that the authors had reached the conclusion that high-speed excitation would not fit the bill but inherent regulation was what would be required. Again I must take issue with them in this matter and state that in my opinion they have reached an erroneous conclusion and their error is mainly due to their failure to perceive that the so-called static-stability problem is in reality one of transient stability.

I shall first show by means of a simple mechanical model that if generator and motor are provided with perfect regulators, no matter what their characteristics, they will furnish power up to the stability limit of the line itself. The model which I have in mind is quite simple and was devised by S. B. Griscom. If two sticks pivoted about one point are connected at the two ends by an extensible elastic string such that its linear extension is proportionate to its tension, and if torque be applied to one member the restraining torque on the other member will represent the power output of a line. The applied torque is the power input. The above applied to a line having no losses but having reactance and distributed capacity. This assumption involves no appreciable error in considering the actions that cause instability because the resistance of the line and generators has only a small effect on the stability problem.

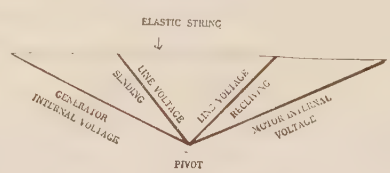


FIG. 3

One may picture one of these pivoted members attached rigidly to the shaft of a motor and the other to the shaft of a generator. The motor drives the generator at constant speed, using this device as a mechanical transmission. As the generator load increases, the elastic connection would be extended in such a way that the sine of the angle between the two members will increase in proportion to the load. If we keep on loading the generator, the angle between the two members will finally become a right angle, at which point the mechanical transmission system will have reached its maximum ability to transmit power and the system will become unstable.

Now the internal voltages of the generator and motor may be represented by two additional sticks (as shown in the accompany-

ing illustration) as extensions of the transmission line beyond this angle. The terminal voltages are kept constant; that is to say, the length of the original two pivoted sticks. As the angle is increased, the elastic line is kept straight by increasing the sticks representing the generator and motor internal voltages. Using this model, it can be shown that the torque at the generator will reach its maximum when the two members representing the terminal voltage of the transmission line are at an angle of 90 deg. with each other.

I have made no restrictions as to the characteristics of the generators and motors except in the matter of losses as in the case of the transmission line, but it is easy to show by means of the model that the rate at which the internal voltage must be increased with increase of load is very much influenced by the internal characteristics of the machines, and if we make the internal leakage impedance low, we shall not require to have as great a range of excitation.

Objection may be raised that ideal excitation systems do not exist and that commercial regulators are too slow. The explanation resides in the fact that the problem is, in reality, not one of static stability but one of transient stability. You must remember that instability involves a change in angular position and this means a change in angular position of the generator rotor and the motor rotor as well as of the line terminal voltage. The electrical angle and mechanical angle are, you might say, irrevocably tied together and to deliver power to a motor through a line at a given excitation requires that they must take up a definite angular position with reference to each other. In my paper, I have pointed out that the angular relation is a continuous function of the power and is therefore suitable for analytical work whereas the voltage at the terminals is a discontinuous function and is not suitable for analytical work.

The fact that the angular positions of the rotors must change with change of load introduces the natural period of the system into the problem of voltage regulation and this means also that sluggishness of the hydraulic or steam governor may have some advantages. If the load is increased, the motor slows down and so does the generator. In slowing down, the motor supplies part of the increased load by inertia. The generator supplies part of the increase in transmitted load by inertia at a slightly lower frequency, so that matters are improved from a stability point of view since, during this stage, only part of the increased load must be transmitted and also because it is transmitted at an appreciably lower frequency. While this is going on, the regulator has had time to get in its work and if the angular change is not too great, the voltage regulator will catch up before the angular displacement has reached the point where the system will pull apart at the increased value of load. Theoretically, this may be carried out close to the limit of stability of the line, providing the load increments are not so great as to cause large swings.

The authors have made no mention of the effect of the characteristics of the load and have merely touched on the improvement to be obtained by changing the generator characteristics, dismissing it with a statement that it will prove too costly. I wish to take exception to this statement and to say that such changes can be made with a small increase in cost over that of standard generators and the increase in the ability of the system to transmit power will more than counterbalance this added cost. Such generators are immediately available and, with specially designed high-speed exciters, will permit of operation of transmission lines with a high stability limit.

In regard to the problems of internally compensated machines, much progress has been made along these lines, but since it is still in the development stage, very little can be said about it at present. It is possible to compensate a generator completely and even to extend this compensation to cover the impedance of transformers so that the generator has the characteristics of the infinite system of which Mr. Doherty and Mr. Dewey speak in their paper; but there are grave questions to be considered in the application of such machines. The rapid retardation and acceleration, caused by short circuits, and the subsequent clearing of the lines may produce mechanical stresses of great magnitude. In all probability some limiting device will be needed to limit the amount of current that can be delivered above a certain value.

Regarding the matter of transients due to short circuits, I agree with the authors that experience has shown that in existing systems with suitable relay protection, short circuits do not constitute a serious problem in operation. However, they make the statement that experience is the best guide and that calculations are always made on the basis of conservative premises and are therefore too pessimistic. The transient condition under short circuit will undoubtedly be the factor which will determine the ultimate rating of a transmission line and it behooves us to avoid being so conservative that our results are pessimistic.

I believe that we can or will be able to compute, with a fair degree of approximation, the results of a short circuit either to ground or between phases if we are provided with proper data as to ground resistance and load characteristics. I am further willing to go on record that we shall be able to install apparatus that will enable us to approach within a reasonable distance of the effect of an infinite system, not only on a straight-away transmission but also for one using intermediate synchronous condensers so that, with the latter system, the stability will be determined by the weakest section.

The automatic voltage regulator is not a hopeless problem for it is assisted by the fact that it takes time for the system to change its angular position whereas the terminal voltage changes instantly. Moreover, the internal reactions are resisted by inherent flow of exciting current. Therefore, the voltage regulator has time to act before the system gets beyond control.

P. H. Thomas: Mr. Fortescue, with his usual skill, has developed generalized equations for showing the theoretical limits of stability in electric systems containing synchronous machines.

The most difficult and illusive part of the problem of stability is the determination of the numerical value of the parameters of stability in particular cases and especially for the pendulum action or the tendency to overswing when a change of load in a system or its equivalent requires a new position of equilibrium. The principles involved are well understood and at least one analytical and one electric analog method have been proposed. These, however, are merely methods of overcoming the mathematical difficulties of the solution and still leave untouched the difficulty of properly evaluating the factors of losses and damper currents.

As is well known, any damper current set up by an advance or retreat in the position of the rotor with regard to the revolving field of the stator will tend to reduce, temporarily, the forces driving the rotor toward its new position of equilibrium and similarly, if the rotor over-shoots, these damper currents tend to restrain the over-swing. If sufficiently powerful, these forces may render the swing of the rotor dead-beat. The conditions governing the effect of these damper currents, which will usually be of very low frequency, should be fully studied to see what can be done therewith to restrain the overswing.

These damper currents should be controlled by the resistance of the damper rather than its reactance, but subject to this limitation the damper resistance should apparently be as low as possible. The field winding, having by far the greatest weight of copper surrounding the field poles would naturally have the most effective damper action.

While Mr. Fortescue has given a definition of stability which is entirely logical, we shall ultimately need something further; viz: a standard test or criterion to be satisfied by any particular system to insure reasonable continuity of operation.

It is yet too soon to offer such a criterion for actual adoption, but ultimately something in the nature of an overload to be taken at a certain power factor, or a drop of voltage (taking account of both ends of the line) that must be sustained without falling out of step, will be required.

It is gratifying that much has been done to render the terminal apparatus more responsive to its duties—but still more is desirable and no doubt possible, on account of the dominating importance of the cost of the line as compared with the cost of regulating and exciting means.

R. E. Doherty: I agree with the general point of view expressed by Mr. Fortescue—namely, that the lack of any great amount of trouble from instability up to the present time should not be interpreted as evidence that such a thing is not possible with longer lines and greater power; that, in any study of the problem, all elements of the system, including generators, exciters, condensers, lines, etc., and not merely one element of it, should be considered; that the problem involves two fundamentally different "states" of operation—"transient" and "steady"—during which the operating characteristics of the apparatus are different. I also agree with the general exposition regarding the angle-power relations, only in so far as it gives a physical, qualitative picture of the phenomenon. I strongly endorse his appeal for reliable information regarding ground resistance and would add an appeal for recorded data and system experience during single-phase short circuits. And, finally, I endorse the view that the mathematical, or even graphical, determination of stability of such system networks as comprise our modern power systems, is quite beyond the range of practical possibility. For these cases an equivalent system from which the required values can be obtained by test becomes necessary—just as for the same reason, it is necessary to thus determine short-circuit currents in complicated networks.

Such methods are available; the equivalent system proposed by C. A. Nickle[6] affords a valuable means of studying the power oscillations during transients, and the scheme proposed by Spencer and Hazen[7] affords a means of testing steady state power limits with practical accuracy. The latter method assumes sine-wave relation between power and angle, and is, therefore, roughly correct for maximum power studies. Nickle's method, however, in its present state of development, assumes linear relation between power and angle, and is, therefore, limited in this particular application to a study of the behavior of the various components of the system during those transients which do not involve power swings beyond the point where the linear relation ceases to hold. However, there are many interesting and important phenomena bearing on stability which can thus be determined; and if a circuit element giving the sine-wave relation is found, the maximum power can also be determined. The company with which I am associated is now completing the development of both of these facilities. While, of course, further improvements are ahead, the present development provides a very helpful aid, and, in my opinion, is a significant step forward.

There are a few points in the paper with which, if I interpret them correctly, I do not agree. They are relatively unimportant with respect to the general problem to which I have referred above, but have importance only in numerical calculations. I refer to the author's statement that the steady-state limit depends upon the leakage impedance and not upon the synchronous impedance. Making due allowance for saturation, which, in effect, reduces the impedance, the steady-state, ultimate power limit at normal voltage is determined by synchronous impedance, not by the leakage or "transient" impedance. A steady-state, hand-controlled test, giving a family of voltage-power curves, (as in Fig. 3 of the paper by Mr. Dewey and myself), shows the same power maxima as determined by automatic regulator tests, and as calculated, using synchronous reactance. While it is possible with an automatic regulator, as it is not by hand control, to throw on suddenly loads equal to the ultimate maximum steady-state power, it is nevertheless not possible, according to our tests and conception of the problem to carry significantly more than that by using a regulator actuated by the alternator terminal voltage and operating on a shunt- or compound-wound exciter of quick response. This is discussed fully in our paper.

In discussing the group of papers by Mr. Fortescue and his colleagues at the Midwinter Convention in 1924, I stated power limits which "in the present state of engineering knowledge" I considered to be justified. I said: "We must neither gamble that a voltage regulator will be able to insert a supporting prop under an otherwise falling system, nor depend for stability during load transients upon possible momentary favorable conditions due to momentary and field transients." Now the intensive study and investigation of the past year and a half has shown what we did not then know—that, up to the ultimate maximum power value, as determined by tests under hand control, the regulator can be depended upon to insert "the supporting prop," but not beyond that limit. I understand the author's statement to be that the regulator makes it possible to carry a constant load significantly greater than the above maximum; with this I disagree.

I do agree with the author that the object sought with an excitation system is to obtain the same characteristics as would be afforded by a machine which would inherently maintain constant flux linkages—one in which the field and damper resistances were zero. To say the same result would be obtained by an exciter of quick response which holds the alternator field approximately constant is in all respects parallel to the statement that if the terminal voltages at both ends of a line were held approximately constant by a regulator (as they can be, even by hand control, with gradual increases of load) the ultimate maximum power would be that of the line alone, *i. e.*, all limitations in the generator would thus be compensated, which obviously is not true. Yet the two cases essentially involve the same elements. It can be shown[8] that, following a load change, the flux change of the alternator field, $\frac{d\phi}{d\,t}$, is not zero, but essentially negative, unless a series negative resistance is introduced in the alternator field circuit. A method for obtaining this is described in our paper. A shunt- or compound-wound exciter, of however quick response, does not have this characteristic. Fortunately, however, for any load up to the ultimate steady-state limit at normal voltage, the ordinary exciter and regulator usually suffice; and this steady-state limit cannot, so far as our study and tests show, be increased by speeding up the exciter magnetically.

R. J. C. Wood: The main reaction I get from these papers is a feeling that perhaps we are using the wrong term when we talk about instability. We are not, ourselves, putting up the money to build these big systems, and I think that anything which suggests unduly, a weak point in transmission should be avoided. I do not mean by that we are to conceal the truth in any way, but there is a psychological effect produced by the word "instability," which I do not think is produced when we talk about power limit.

What we are getting at is the power limit of a system. There are various things which limit that power; the current may be so great that the wire will fuse and fall in half, or it may be this "instability" that we are talking about.

If you go out to buy an automobile you take the automobile out and try it and you run it up a hill and the hill is of increasing steepness. After a time that car just lies down and quits.

6. Oscillograph solution of Electro-Mechanical Systems, by C. A. Nickle, JOUR. A. I. E. E., p. 1277, Dec. 1925.

7. The Artificial Representation of Power Systems, H. H. Spencer and H. L. Hazen, A. I. E. E. JOURNAL, January, 1925, page 24.

8. Exciter Instability, R. E. Doherty, A. I. E. E. TRANSACTIONS, 1922, page 767, eq. 30.

You have not an unstable automobile; you simply have reached the limit of its ability. Perhaps you kill the engine; perhaps you spin the hind wheels. That might be an illustration of the generators falling out of step.

It would be better if we could think and speak of this more in terms of power limit; everybody is familiar with the idea of a limit of endurance, both humanly speaking and as regards apparatus and machinery.

Roy Wilkins: I am employed by a company owning an interconnected system of upwards 8000 mi. of line 60-kv. and over, and with a total generating capacity of a little over 880,000 kv.-a. The connecting rotating load is about 2,000,000 h. p. At different times there have been tested 110-kv. lines up to 500 mi. in length in operation and carrying load, and loops as long as 350 mi.

I should like to point out certain road signs in the line of "don'ts" for people who, in the actual power industry, take up the study of power limits or instability as it has been called. First, don't worry about anything except the actual operating conditions. You will find trouble enough without running into any weird combinations which are impossible operating conditions. Second, don't expect to simplify the problem and still check the performance of a complete transmission system, because in a transmission system, every piece of connected apparatus has certain characteristics. These characteristics are all in their proper places, proper order and proper values. Any simplification means a certain amount of error.

At the present time, there is too little known about circuit-breaker operations, corona, $W R_2$, impedance, load character and load power factor, together with certain cases of trouble as grounds, etc. As a passing note, nobody, at the present time, knows exactly what "load power factor" is. I haven't been able to measure it in a year and a half. The final result will come from a mass of accumulated operating data just as in the past for the final solution the twenty-year old problem of a grounded-neutral system came not from brilliant mathematics or special studies, but from the final check and the actual operating procedure of a great number of operating systems.

F. G. Baum: If you will read the TRANSACTIONS of the Institute of twenty years ago you will find that the problem of stability was then one of very great importance and a great deal of work was done on it at that time. The reason for its importance was this. The Stanley Company made for operation on the first long transmission systems, an inductor type of generator which had no revolving coils of any kind. The generator had 100 per cent reactance. It was good for the conditions which then existed, since we had only air switches with which to open the circuit. If there was a short circuit, the voltage dropped to zero and you could open the circuit with the air switches.

Generators were actually advertised as being capable of being short-circuited without damage and only a few years ago many engineers were specifying that the short-circuit current should not be over so many times normal current.

We are now talking transmission-line stability again, and the generators are the main element in it. The transmission line will take care of itself if you will take care of the generators. The reason we are talking so much about instability is because we have flashovers, or expect them, and therefore want to be ready to take up and quickly replace the difficulty caused by the flashover. In other words, the trouble now is with flashovers, while twenty-five years ago it was that we didn't have any switches. At the time the Stanley generator was put out I was in charge of the operation of the Pacific Gas and Electric Company in which we had a number of these generators and the regulation was very poor. The voltage variation under normal operations was so bad that we couldn't operate lights at the same time as motors. Something had to be done so we applied to all the synchronous apparatus an excitation in proportion to the load. All the d-c. load current was taken around the exciters and the voltages built on the d-c. exciter in proportion to the load.

At that time I also worked out a regulating scheme for the a-c. generators which would build up the generator voltage in proportion to the drop in voltage due to the load, which as you know is practically $I \sin \theta$. I wasn't popular for proposing that because the generators were being sold because they had poor regulation, and I proposed to make them good.

For the last year and a half we have been making quite elaborate tests on power limits of transmission systems, and I agree with Mr. Wood that it is power limits and not instability which we are talking about. We don't get instability unless we have troubles outside of those that are expected and most of those come from flashovers. Stop flashovers and you won't get the instability.

The tests made have checked calculations very, very accurately. Early last Spring we calculated the power limit on the Pit River System as 185,000 kw., using a power-angle diagram, which you will find in the *Electrical World* in 1902. The limit of the Edison system under actual operation has been found to be 183,000 kw. and if you will allow for the increased length of line and decreased frequency the results check.

I want to express surprise at the suggestion made in Doherty-Dewey paper for the use of series capacity in the transmission line. You can do that in a radio system but to consider it seriously for a transmission line seems unreasonable.

The most important part of the transmission system today is the oil switch and relays. If we didn't have them today we couldn't operate our transmission systems. Any electric power system of high or low voltage and without proper relays, switches and fuses to eliminate defective line sections is inoperative. I think you will agree with that, so I say, work on the oil switches and relays. First work on the flashovers, and get rid of those so the switches won't have any more to do than necessary. Then when you get through with that, static stability will be the criterion of your power line and not transient stability.

A statement has been made with reference to the limitations of long-distance power transmission, which was quoted in a morning paper. The statement was that with the present apparatus (and present state of mind, especially) 300-mi. transmission is questionable of economic results.

I challenge that statement. I think it should never have been made. Any man who sets a limit at the present time on power transmission either does not understand the problem or perhaps he is purposely making the statement for some other reason.

I wrote a paper for this meeting which I didn't submit because certain developments afterward made it advisable to add other information. The first sentence reads: "The natural and approximately the economic load per circuit for load transmission is given by the equation $P = 2.5\ E^2$."

If 220 kv. will not do the work, we can go to 330 kv., or some other reasonable voltage, and if 330 kv. won't do it, we can go to 440 kv. When I say that I am saying it in view of the intense study made in the last two years on insulation, coupled with the results obtained on the present system of the Pacific Gas & Electric Company, operated at 220,000 volts. It is the most successful piece of work we have undertaken, and the power is transmitted about 300 mi.

To have a real natural transmission system, you must balance the magnetic energy all along the line with the electrostatic energy. To develop that you get this equation, $I = E\sqrt{\frac{C}{L}}$. I want to call your attention to the importance of this equation. I think that equation is more important than Ohm's law or any other in electrical engineering. It is a

fundamental equation. Nature tries to transmit power with the conditions given by that equation.

Now, if I want more current, I can do three things; Raise the voltage, lower the reactance or increase capacity. Most people will recognize that if you lower the reactance you will immediately get increased line capacity, but they do not appear to recognize that if you increase C you get the same results practically. I can reduce L to one-half and multiply the amount of power by $\sqrt{2}$; I can change C by doubling its value and also increase the power by $\sqrt{2}$.

Regarding line insulation, with the study we have been making in the last year and a half, I am satisfied that when we want the 330 kv. we can get it. We started this work early in 1924, not because of any troubles on our present 220-kv. transmission lines, but because we didn't want to be caught like we were in 1912 when we put in the 110-kv. lines, and later found troubles we didn't know anything about. We decided in 1924 that we would make a thorough study of insulation. The Westinghouse Company has supported that work on insulation, and the Pacific Gas and Electric Company is cooperating in the long-line tests and the practical tests which we find necessary.

So the first thing was to decide how to get at the matter of the mechanism of flashovers. I decided, after several years of study, taking probably thousands of flashovers and arriving at no mental picture of what was happening, that we had to get a reliable picture of what actually was happening whenever we had a breakdown. To get that we decided that we should probably have to get at it from a d-c. standpoint, projecting the electrons through the air, and if possible taking their pictures on the way. They are fast-moving and don't pose very long.

The pictures we have taken will I believe give a mental picture of the insulation of the air such as we have not had and I believe the work done and being done will tell us the true story of line insulation.

R. E. Doherty: The extensive discussion indicates a keen interest in this important subject, and serves the very helpful purpose of focusing attention on those points which have not yet been generally agreed upon. The more they are discussed, the more they will be studied and the sooner will the various interested engineers agree upon the more important details. While perhaps there is not at this time *universal* agreement upon even the more fundamental aspects of the problem, there has been, I think, for the past two years general agreement on these fundamental aspects by those who have given the matter serious study. As I mentioned at the Midwinter Convention at Philadelphia, in 1924, the fundamental theory underlying the problem, and the equations arrived therefrom, are used by all informed engineers. Divergence of views enters only when assumptions are made regarding numerical values for a particular case. More specifically, disagreement centers, not about the transmission-line theory or the general equations of the system, but about faulty understanding regarding internal characteristics and constants of synchronous machines. Although different views regarding such machine characteristics apparently result in different estimates of maximum power which can be transmitted over a given system, I am not sure that this difference is as great as might be expected from the tone of the discussion. Messrs. Fortescue and Evans say that the calculated values in our paper are too low, but they do not indicate what these values should be. And I believe that in any definite proposed undertaking, their conclusions as to the practical feasibility of carrying out the given proposal, would not be significantly different from ours. Indeed, in more recent proposals where such parallel studies have been made, the conclusions have not been widely different. All of which indicates, of course, that the protracted discussion regarding certain alleged, weird behavior of synchronous machines is somewhat of a trifling character, and not of the importance which engineers not familiar with such details might be led to suspect.

I shall attempt to answer the questions raised regarding our paper, although most of them could have been answered by referring to statements in the paper. Mr. Thomas believes that it is not likely that the charging current of a long line will be a detriment under practical operating conditions. It may, indeed, be a great advantage provided the generating capacity at the end of the line is sufficiently large, as clearly shown in Fig. 2. But this is not a matter of opinion; the extent of its effect can be easily computed for any given case. It must not be concluded just because calculations made on the basis of constant terminal voltage show a larger power limit with the normal line capacitance than without it, that the same result would obtain with synchronous apparatus of a kv-a. capacity comparable with the load to be transmitted.

Mr. Griscom states that he does not understand why synchronous apparatus becomes inherently more powerful during transients. The reason is that, for the moment, the *transient* reactance, instead of the *synchronous* reactance, determines the power characteristic of the synchronous machines. The ratio of synchronous reactance to transient reactance in ordinary commercial synchronous machines is of the order of 5 to 1. It may be as low as 3 to 1, or as high as 10 to 1. In other words, in rough values the synchronous reactance is about 100 per cent, and the transient reactance about 20 per cent. Thus the machine in such a transient state is decisively stiffened up. Mr. Griscom's question would probably be removed by reading over the paper—under the heading "Transients."

He also questions whether the slope of the voltage-power curve determines the degree of stability. If the slope is zero at all values of power, it merely indicates that the voltage of the bus under consideration is not affected by any power change whatsoever, regardless of whether the synchronous machines constituting the infinite bus are of zero inertia or infinite inertia or any value between these extremes. Mr. Griscom's statement is correct that when $\frac{d\,E}{d\,P}$ approaches infinity, $\frac{d\,P}{d\,T}$ approaches O; but this is not, as Mr. Griscom states, because $\frac{d\,P}{d\,\Theta}$ is limited by the mass of the synchronous machines, but because at that moment the electrical characteristics are such that the power is not changing, although the angle Θ may be changing.

I wish to add a word about this 183,000-kw. story as related by both Mr. Evans and Mr. Baum, and which Mr. Dewey has answered. When the engineers of the country are eagerly waiting for every additional fact of operating experience bearing on this subject, it seems unfortunate, indeed, that when some real data do become available, their meaning should be so completely misunderstood or misinterpreted. When the sending end wattmeter reads 183,000 kw. and the receiving-end meter reads 135,000 kw., should we say or imply that 183,000 kw. is *transmitted over* the line? And I think that neither Mr. Evans nor Mr. Baum would, after serious thought, adduce that test (which our calculations check) as evidence that our calculated values are much too low. In Mr. Evans' published work, he calculates, as most every one does, the receiver-end, not the sending-end, power.

Mr. Evans raises two other points: One is that the maximum power can be increased by reducing the reactance of the generator; the other, that Fig. 2 might be misleading. As to the one, the authors heartily agree, as presumably every one else does. Nobody would question that. The question is *how* will you decrease the reactance. Mr. Evans is referred back to the paper to the heading "Design," where this matter is fully discussed. The generator capacities given are based on present-day practise—synchronous reactance approximately 100 per cent. Nothing

would be gained by cutting the ratings to, say, one-half, thus reducing the per cent reactance to 50 per cent. That would not increase the maximum power. The question is how would one alter the design of a machine of given magnetic dimensions in order to lower the synchronous reactance, and to what extent could it be thus lowered. There could not be much disagreement among informed designing engineers on that point. After that is done, any further reduction must be obtained by increasing the active volume of the machine, or by adding more machines. Thus, as Mr. Evans says, and as the paper clearly points out, "quite marked increases in the stability" can be obtained in these ways, but there are perfectly obvious reasons, as the paper also points out, why this process cannot be extended far enough to satisfactorily solve the problem.

The other point raised by Mr. Evans is well founded. The authors acknowledge that the title of Fig. 2 should be more specific, and will revise it accordingly. The illustration refers to a 250-mi. straight-away line with synchronous-motor load.

Mr. Fortescue does not know of "a single case in which a system was thrown out of step by a sudden increase in load, or short circuit due to low excitation." There have been such cases, nevertheless. The September 1919 trouble of the Commonwealth Edison Company, described by Dr. Steinmetz in the 1920 TRANSACTIONS, is one notable example among others.

The authors naturally agree that if an additional line with duplicate sending and receiving apparatus be installed, the maximum power will be increased. Two power *systems* will obviously carry more than one. But that is not the point. Fig. 2 merely shows the relation between generating capacity, number of lines and maximum power. To say, as Mr. Fortescue does, that two "properly designed" systems with "proper size generating stations," etc., etc., will always carry more than one, would hardly bear close scrutiny where costs are regarded; because "proper size" for maximum power may be prohibitive in cost.

It does not require a mechanical model to prove the platitude that if "the terminal voltages are kept constant," the power limit will be the limit of the line itself. But to the authors' knowledge the "perfect regulator" to hold this condition does not exist. When it shall exist, or else some other method than synchronous operation is utilized, it will be time enough to talk seriously about the limit of the line alone. I have discussed this problem of regulation in my comments on Mr. Fortescue's paper.

Mr. Fortescue also bespeaks the gain from changing the generator characteristics. Such changed generators, he avers, will permit of operation with a "high stability limit," but he doesn't say how high. And the whole point, if there is any, depends upon *how high*. He, like Mr. Evans, is referred to the paper under the heading "Design."

They also mention that the authors have not discussed the effect of load characteristics. Loads which are functions of the voltage, such as lights and certain classes of converters feeding a constant voltage d-c. bus, are inherently stable. These have a maximum power, but that is not the limit of stability. Indeed, there is no stability limit with a plain impedance load. The shaft load of induction and synchronous motors is independent of voltage, and for these, the maximum power limit and stability limit coincide. Thus, a composite load would have greater stability than a pure shaft load of the same amount.

H. H. Dewey: In closing, I shall take up some of the points that have been brought up in the discussion of the paper by Mr. Doherty and myself.

Mr. Thomas in his discussion brought out a point in regard to the relation of the cost of the terminal apparatus to the cost of the line, pointing out that the line cost was very high per kilowatt. It might run to $125.00 per kilowatt, whereas the terminal apparatus, generators and motors, would be very much less than that, perhaps $8.00 or $10.00 per kilowatt, and that since the terminal apparatus was an important factor in the power limit of the completed system, the place to work to extend our power limits was on the synchronous apparatus. I agree with that thoroughly, and we can do considerable along that line.

Mr. Evans and Mr. Fortescue spoke of the possibilities of synchronous-apparatus improvement as a thing about which we were unduly pessimistic in our paper, that is, the question of what could be done to increase the power limit of terminal apparatus. Our paper did not stress that point for the reason that it seemed obvious. In presenting the curve given, showing the breakdown of a given generator and a given motor, it is quite apparent that the power limit is determined by the size of the generator. If we had a generator of double the size, or a motor of double the size, we would get double the power. In line with Mr. Thomas' suggestion then, since we can put on generating apparatus for $8.00 or $10.00 per kilowatt, we can obviously increase the size of the generator until we strike an economic balance between the size of the generator and the capacity of the line.

Now, the size of a generator is determined by its characteristics. We would fool ourselves if we tried to take a 10,000-kilowatt generator and cut its reactance in half, change its field, style, etc., and still call it a 10,000-kilowatt generator. It wouldn't be a ten thousand any more; it would be fifteen or twenty, and it would cost more money to build it. That is an obvious thing that we did not stress in our paper. Since generating and receiving apparatus is a large factor in limiting the power that can be transmitted over a system, everything possible should undoubtedly be done to improve their characteristics.

The paper tried to cover the essential points in determining what a given set-up would give. There was a point that Mr. Evans brought up and Mr. Fortescue also, in their discussion, in regard to the effect of charging current of transmission lines. They took issue with Mr. Doherty and myself in stating that charging current was an actual detriment. They evidently did not read our discussion of that point very carefully.

With given apparatus, with a given generator, with a given receiving-motor load, and a given voltage, at each end of the line, which we always have, charging current *is* an absolute detriment. We reduce the amount of power which can actually be transferred from the generator to the receiver end, no matter what the relation of charging current of the line to the generator. The charging current of the line on a high-voltage system will actually reduce the amount of power you can transfer from the generators to the motors, because it reduces the excitation of the generators and motors.

Mr. Evans brought out a point in which he indicated that our calculations on a 250-mi. line were in error in that it was considerably less than the value that had already been obtained in practise by the Southern California Edison Company. He stated that our calculations showed the limit to be 115,000 kw. whereas they obtained 183,000 kw. The calculation is 120,000 kw., not 115,000 as read from the curve by Mr. Evans. We have made a calculation of the Southern California Edison System based upon data furnished by Mr. Barre which showed 183,000 kw. Our check calculations, made in the same manner as our calculations in the paper, came within 5 per cent or thereabouts of the same results.

The big difference in these values comes in this respect: The 120,000 kw. shown in the paper was receiving load. The 183,000 kw. obtained in actual practise on the Southern California Edison Company's system was at the generating end. At the time they had 183,000 kw. input they had 135,000 kw. output. Thus, we have an error of only 120,000 kw. to 135,000 kw. and there is a difference of 20 per cent in frequency, that is, 50 instead of 60 cycles, which brings it to almost exactly the same thing.

Mr. Wood spoke of the term that has been quite often used to describe "power limit;" that is, "instability," and sounded a warning against its use. I agree with him thoroughly on that. It was for that reason that the title of our paper was made Power Limit. Power limit is something that is perfectly harmless,

and I agree that the use of the word instability is likely to cause concern where concern is not necessary.

Mr. Fortescue's discussion was quite lengthy and very helpful. He took issue with some parts of our paper. Some of these points I did not quite digest. Some of them made me rather think that he was saying the same thing we were saying only in different words, particularly as he laid very great stress on the effect of voltage regulators. I agree with him thoroughly that the regulator is a very important thing, and is so much more important than we originally thought that it makes a great deal of difference in the ultimate capacity of the transmission system.

We have very few real things to worry about. I agree with Mr. Wilkins that the final solution of this problem is going to come in the data that we get from actual operation, but so far the data of actual operation, where we have been able to obtain data, have checked so closely with our present methods of calculation that we feel we are in a position where it will be possible to predict what will happen to any given system. The more complicated the system, the more difficult it is to calculate, and when we get such complications, we must resort to some scheme such as Mr. Nickle has described[9], just as we reach the limit of the possibility of calculating short-circuit current on a network such as described by Mr. Wilkins with 880,000 kw. of generating capacity and thousands of miles of interconnected transmission line. That would be a hopeless case to calculate the short-circuit current, but we have calculating machines that arrive at these values very closely. We can likewise use the Nickle calculator, or some other device to arrive at our stability problem. We are not worrying about the question of stability or power limits; we know pretty closely how to calculate them, and it is very essential that we do so, as the amount of power that can be carried over a given line greatly influences the cost of delivered power.

C. L. Fortescue: In regard to Mr. Thomas' discussion, he emphasizes the effect of damping factors. In our calculations we try to work in the effect of the damping factor as much as possible, but Mr. Thomas remarks that if you increase the damping factor sufficiently the machine will be critically damped. We know that in practise this condition is never met. We have records of power swings and they are as far as we know never critically damped.

As regards Mr. Doherty's discussion I think we are substantially in agreement. I think an explanation of the differences in view might be somewhat as follows:

Two investigators have approached this problem from somewhat different angles, and while there is no disagreement in the fundamentals of the problem, there is a little apparent disagreement in what might be termed derived ideas.

The problem of stability involves so many factors, the speed of the exciters, the speed of the regulators, the inherent tendency of the machines to correct themselves, etc., that it is quite excusable that there should be a slight difference of opinion.

Now, I think you might say that Messrs. Doherty and Dewey and myself agree on what should be. We probably agree pretty well on what actually is, but we disagree somewhat in regard to what may be or might be, Messrs. Dewey and Doherty putting the "might be" a little closer to the "is," and I myself putting the "might be" a little closer to the "should be."

I hope that the result of our investigations will finally bring us both to an agreement on the "might be" and that the "might be" will finally come closer to the "should be" than Messrs. Doherty and Dewey place it at present. That is my hope. I am quite open-minded about this.

The final decision about this particular question will undoubtedly come about from actual work in the field and in the laboratory. We shall, of course, make calculations and analyze these results and there is no doubt at all that we shall finally come to a substantial agreement. In that day I hope we will be very close to the "should be."

9. "Oscillographic Solution of Electromechanical Systems," by C. A. Nickle, Jour. A. I. E. E., December 1925, p. 1277.

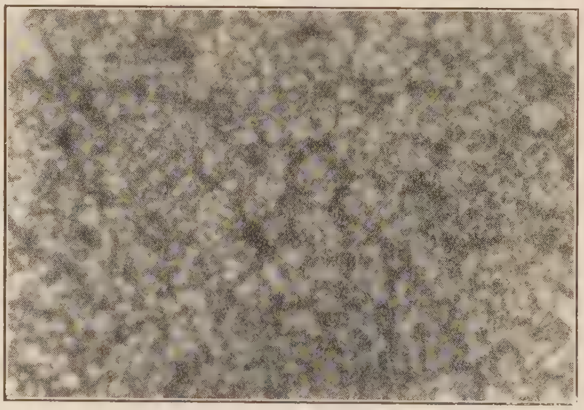
ILLUMINATION ITEMS

By the Lighting and Illumination Committee

INTERESTING ASPECTS OF THE INSIDE FROST LAMP[1]

For some twenty years or more the advantages of frosting an incandescent lamp on the inside of the bulb have been appreciated by illuminating engineers but until recently no satisfactory method had been devised whereby this frost may be applied to the *inside* of the lamp without at the same time greatly weakening the structure of the bulb.

An inside frost is etched into the glass and this etching process causes minute cracks or splits to appear just underneath the surface of the glass. These cracks weaken the strength of the glass in practically the same way as does the scratch made by the hard point of a glass cutter. Moreover they spread easily and cause premature failure just as does a crack in a plate-glass window or in a steel-truss member. It is a well-known fact, however, that if a round hole is drilled at the end of the crack or split in the latter cases the window will be less likely to become entirely broken and the steel supporting member will withstand a greater weight. In like manner, when the inside frosted lamp is subjected to the proper treatment, the entire area of the inside surface will become etched in such a manner as to round out the bottoms of these cracks. The effect in this action is to restore the strength of the bulb to its former value, and the inside frost thus becomes a thing of

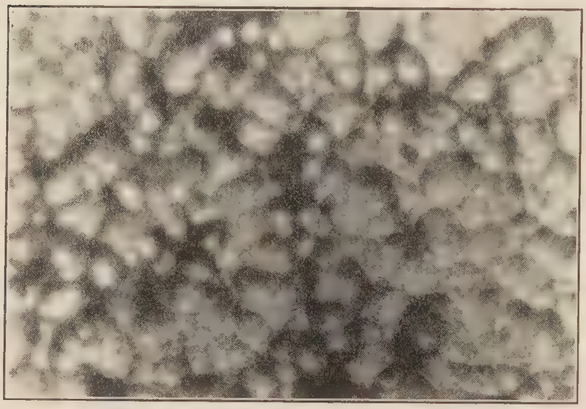


Micrograph Showing Inside Frosted Surface of Weak Bulb

1. Marvin Pipkin, Chemist, National Lamp Works of General Electric Co., Nela Park, Cleveland, Ohio.

practical importance instead of theoretical conjecture. The accompanying micrographs show the frosted surface before and after this strengthening action takes place.

The diffusion of the light by the inside frost is obtained by prismatic refraction with comparatively little loss. In fact, the inside frost allows an even greater



Inside Frosted Surface Treated to Restore Strength

portion of the light to pass through than does a similar frost on the outside of the lamp. This is due to the fact that the multiple internal reflections are not so numerous in the inside frosted lamp because the rough, interior surface does not reflect any considerable portion of the light back and forth inside the lamp, as is the case with the outside frosted lamp. Moreover, the relative absorption of the inside frost does not increase so rapidly with the life of the lamp as do other diffusing media. The relative degrees of absorption of the various diffusing media are shown in the following table for new lamps as well as for lamps which have burned for approximately 800 hours.

TABLE NO. I

	Approximate Initial Absorption in per cent of Clear Bulb Light Output	Absorption After Burning in per cent of Clear Bulb Light Output
Inside Frost per cent	1– 2	1– 5
Sand Frost (Outside) per cent	5–10	10–20
Spray Frost (Outside) per cent	5–10	10–20
White Mazda (Sprayed) per cent	10–15	15–30
Opal Glass	10–20	15–30

The light absorption by the inside frost is of little importance when the material reduction in the glare over that from a clear bulb lamp is considered. Other advantages of the inside frost such as the smooth exterior surface of the bulb and the resulting ease with which it may be cleaned, were mentioned in the July issue of the Journal.

When unlighted, the new bulb appears to be a light gray with the property of blending in a harmonious manner with the color of the background that is entirely lacking in the other types of bulb finish. The color of the background is diffused within the lamp, itself, giving it a faint corresponding tint. Because the inside frosted bulb will blend harmoniously with its background, it is hoped that its use will eliminate the necessity of supplying tinted bulbs where the unlighted appearance of the lamp has been an important factor and where the cold white appearance of the outside frosted or coated lamps has been objectionable.

CHAPTERS ON LIGHT

To most of us, the high school physics courses of today are removed somewhat from our general trend of thought. Nevertheless, let us consider them for the moment. They are essentially the same as they were some years ago—fair enough, perhaps, in some branches of physics since Archemedies' principle, Charles' and Boyles' laws, Newton's laws of motion and the like, are fundamental truths which will never change as far as we are concerned. But what about these chapters in the physics texts which deal with light—that vision-giving wave motion by means of which we are able to see what goes on about us?

Unfortunately, the majority of high school physics texts treat the subject of light in a rather dry and scientific manner which quite frequently presents no direct appeal to the average high school student. Realizing this, the Illuminating Engineering Society has prepared a booklet, "Chapters on Light," which is recommended for inclusion in physics text books. The preparation of this booklet has been sponsored by several of the most prominent illuminating engineers of the country and it is therefore up-to-date in every detail. Furthermore, the presentation of the subject matter is such that the average high school student will be directly interested in the practical applications of lighting and illumination to every-day life, and he is, therefore, much interested in the laboratory experiments which will really be of some practical benefit to him.

"Chapters on Light" will make an excellent addition to present text books and may be used in part as a substitute for present material. It is hoped that this booklet will be used more extensively in high school physics courses as it will undoubtedly tend to increase the students' interest in correct lighting and its application.

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

A. I. E. E. Nominations

The National Nominating Committee of the Institute met at Institute headquarters, New York, December 3, and selected a complete official ticket of candidates for the Institute offices that will become vacant August 1, 1926.

The committee consists of fifteen members, one selected by the executive committee of each of the ten Geographical Districts, and the remaining five elected by the Board of Directors from its own membership.

Those present were: H. P. Cramer, Portland Ore.; W. P. Dobson, Toronto, Ontario; Gano Dunn, New York, N. Y.; G. Faccioli, Pittsfield, Mass.; M. M. Fowler, Chicago, Ill.; J. E. Kearns, Chicago, Ill.; M. M. Koch, Denver, Colo.; E. B. Merriam, Schenectady, N. Y.; L. F. Morehouse, New York, N. Y.; A. G. Pierce, Cleveland, Ohio; T. C. Ruhling, Kansas City, Mo.; A. M. Schoen, Atlanta, Ga.; Harold B. Smith, Worcester, Mass.; N. W. Storer, Pittsburgh, Pa.; H. S. Warren, New York, N. Y. (representing Pacific District); and National Secretary F. L. Hutchinson. Mr. Gano Dunn was unanimously elected chairman of the committee.

The following is a list of the official candidates:

FOR PRESIDENT

Cummings C. Chesney, Manager and Chief Engineer, General Electric Company, Pittsfield, Mass.

FOR VICE-PRESIDENTS

NORTH EASTERN DISTRICT: H. M. Hobart, Consulting Engineer, General Electric Company, Schenectady, N. Y.

NEW YORK DISTRICT: George L. Knight, Mechanical Engineer, Brooklyn Edison Company, Brooklyn, N. Y.

GREAT LAKES DISTRICT: B. G. Jamieson, Engineer of Inside Plant, Commonwealth Edison Company, Chicago, Ill.

SOUTH WEST DISTRICT: A. E. Bettis, Vice-President, Kansas City Power & Light Company, Kansas City, Mo.

NORTH WEST DISTRICT: H. H. Schoolfield, Chief Engineer, Pacific Power & Light Company, Portland, Ore.

FOR MANAGERS

F. J. Chesterman, Chief Engineer, Bell Telephone Company of Pennsylvania, Philadelphia, Pa.

H. C. Don Carlos, Operating Engineer, Hydro-Electric Power Commission of Ontario, Toronto, Ont.

I. E. Moultrop, Asst. Supt., Construction Bureau, Edison Electric Illuminating Company of Boston, Boston, Mass.

FOR TREASURER

George A. Hamilton, Electrical Engineer, Elizabeth, N. J.

The constitution and by-laws of the Institute provide that the nominations made by the National Nominating Committee shall be published in the January issue of the Institute JOURNAL; and provision is made for independent nominations as indicated below:

CONSTITUTION

SEC. 31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the National Secretary when and as provided in the By-Laws; such petitions for the nomination of Vice-Presidents shall be signed only by members within the District concerned.

BY-LAWS

SEC. 22. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with Article VI, Section 31 (Constitution), must be received by the Secretary of the National Nominating Committee not later than February 15 of each year, to be placed before that Committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the National Nominating Committee in accordance with Article VI of the Constitution and sent by the National Secretary to all qualified voters during the first week in March of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

F. L. HUTCHINSON,
Secretary
National Nominating Committee

Cummings C. Chesney

Mr. Chesney, official nominee for the office of President of the Institute, was born in Selingsgrove, Pa., October 28, 1863, and was graduated from the Pennsylvania State College in 1885. After teaching mathematics and chemistry for three years he became associated with Mr. William Stanley's laboratory at Great Barrington, Mass., and was one of the original incorporators of the Stanley Electric Manufacturing Company, of Pittsfield, Mass., which developed the well-known S K C polyphase system (Stanley-Kelly-Chesney). Mr. Chesney was vice-president and chief engineer of the Stanley Company from 1904 to 1906, and in the latter year he became chief engineer and manager of the Pittsfield Works of the General Electric Company, which had acquired the Stanley Company. Mr. Chesney has served as Manager and Vice-President of the A. I. E. E., and also upon various committees. He is also a member of various other scientific and engineering organizations. The Edison Medal was awarded to Mr. Chesney in 1921 "for early developments in alternating-current transmission."

Plans for the Midwinter Convention

FEBRUARY 8-11, 1926

A variety of excellent papers will be presented at the Midwinter Convention which will be held in the Engineering Societies Building, 33 West 39th Street, New York, February 8-11, 1926. The entertainment and social features as well as the inspections will be thoroughly enjoyable.

Among the technical subjects to be discussed are transmission stability, protective and control systems, bus and structural construction, electrical machinery, measurements, insulation and dielectric absorption, electromagnetism and electrophysics, communication and sound reproduction, and furnace-resistor design. The list of papers given below shows in detail the topics to be presented.

In the social part of the program there will be an informal smoker on Tuesday evening, February 9, at the Hotel Astor. Some very interesting entertainers will add to the pleasure of this evening.

The dinner-dance on Wednesday evening promises to be even better than the dinner-dances of the past few years which always have been most heartily enjoyed. This event will be held at the Hotel Astor and a Paul Whiteman orchestra will furnish the music. This fortunate combination is an absolute guarantee of an excellent dinner, fine music and very enjoyable dancing.

On Thursday evening an address will be given by a prominent speaker and all should take the opportunity of hearing him.

New York, of course, offers a limitless variety of possible inspection trips and the trips being arranged will be most instructive. Among the places to be visited will be the new Holland Tunnel (the vehicular tunnel under the Hudson River), Broadcasting Station W. E. A. F. of the American Telephone and Telegraph Company, the Edison Lighting Institute of the Edison Lamp Works, the Loening Airplane Factory, Kearny Power Station of the Public Service Electric and Gas Company, Hudson Avenue Station of the Brooklyn Edison Company, Hell Gate and Sherman Creek Stations of the United Electric Light and Power Company, the Bell Telephone Laboratories and a machine-switching central telephone office.

A live convention committee is perfecting plans to assure that all who attend the meeting will have a pleasurable and profitable time. The general committee appointed by President Pupin is as follows: H. A. Kidder, Chairman. H. H. Barnes, Jr., G. L. Knight, E. B. Meyer and L. F. Morehouse. Chairmen in charge of entertainment features are as follows: Smoker, G. W. Alder; Inspection Trips, H. Y. Hall; Dinner-Dance, J. B. Bassett, and Special Meeting, H. S. Sheppard.

Reduced Railroad Rates

A reduction in railroad fares is available to out-of-town visitors under the certificate plan. Under this plan each person requests a certificate when purchasing a one-way ticket to New York. Presentation of this certificate at convention headquarters will entitle the passenger to half-rate fare for the return trip by the same route provided 250 certificates are presented at the convention.

Members should advise their local ticket agents when purchasing tickets of their intention to attend the A. I. E. E. convention and should ask for certificates. Return tickets issued at the reduced rates are not acceptable on a few limited trains. Tickets must be purchased not more than a fixed number of days prior to the opening date of the meeting and return tickets must be used within a certain period after the closing date. Details relative to these dates, etc., can be obtained from ticket agents. Immediately on arrival in New York certificates should be presented to the endorsing officer at convention headquarters.

All Visitors Should Get Certificates

Everyone, whether he will use it or not, should get a certificate if his regular fare to New York is 67 cents or more, because all certificates presented will count toward the 250 required to give reduced fares to those coming long distances.

TENTATIVE PROGRAM OF MIDWINTER CONVENTION
FEBRUARY 8-11, NEW YORK

Monday Morning

Registration
Committee Meetings

Monday Afternoon

Transmission Session

1. *An Investigation of Transmission-System Power Limits*, C. A. Nickle, General Electric Company, and F. L. Lawton, Quebec Development Company.

   Results of theoretical analysis, verified by miniature-system tests, of the power limits of transmission systems. Among the major conclusions are the following: (1) The criterion of stability for all conditions is the steady-state power limit, (2) the charging kv-a. exercises marked detrimental effects on stability, (3) the characteristics of synchronous terminal apparatus are of great importance, (4) improvements can be made by modifying present apparatus design, (5) automatic voltage regulators, suitable exciters and fast relays are essential, and (6) the mercury-arc rectifier as an adjunct in excitation circuits shows real advantages.

2. *Calculation of Steady-State Stability in Transmission Lines*, Edith Clarke, General Electric Company.

   Two simple methods of determining whether a proposed transmission system will or will not be stable for steady-state operation under the maximum proposed load, (1) by means of an equivalent circuit and (2) by means of a circle diagram. Examples are solved to illustrate the methods.

3. *Practical Aspects of System Stability*, Roy Wilkins, Pacific Gas and Electric Company.

   An account of field tests made on a 220-kv. transmission system to determine the behavior of the system under transient conditions. Among several important conclusions reached are: (1) Stability is inextricably entangled with system economics, (2) studies of artificial systems are not adequate, (3) only a certain part of a system's stored energy is available during trouble, (4) proper relay action is vital, and (5) operating distribution of exciting current is a major problem.

4. *Further Studies of Transmission Stability*, R. D. Evans and C. F. Wagner, Westinghouse Electric & Mfg. Company.

   This paper deals with the principal elements entering into the stability problem, such as the action of generators and exciters during disturbances, effect of dissymmetry produced by single-phase short circuits, simplification of load networks, and methods of combining these factors in determining electro-mechanical oscillations following disturbances. Results of calculations are compared with recent tests on the Pacific Gas and Electric Company system. Various methods of improving stability are discussed.

5. *Transmission Systems with Over-Compounded Voltages*, H. B. Dwight, Massachusetts Institute of Technology.

   A discussion of the advantages of causing the voltage at generating stations to be raised by automatic regulation at times of heavy load. Methods of calculation for the transmission line and transformers for over-compounded operation are given. Two methods are given (1) for over-compounded generator voltage and constant receiver voltage and (2) for over-compounded voltages at both generator and receiver.

Monday Evening

Dielectrics and Insulation

6. *Dielectric Absorption and Theories of Dielectric Behavior*, J. B. Whitehead, Johns Hopkins University.

   A review and comparison of all the theories of dielectric behavior and dielectric absorption which are found in existing literature. This is a report made on these subjects to the Division of Engineering and Industrial Research of the National Research Council. An exhaustive bibliography is included.

7. *Theory of Absorption in Solid Dielectrics*, V. Karapetoff, Cornell University.

   The purpose of this paper is to establish certain general relations between (a) the increase in electrical displacement in a solid dielectric and (b) time after the initial displacement which occurs almost instantly after applying a constant d-c. voltage.

The ultimate aim of the theory is to make it possible to correlate and mutually to check experimental data on absorption and dielectric loss and to predict these quantities where no test figures are available.

8. *Ionization Studies in Paper-Insulated Cables*, C. L. Dawes and P. L. Hoover, Harvard University.

Tests data are given in this paper which show the relations among voltage, power factor, watts, capacitance and temperature in impregnated-paper cables and in model cables. A new type of a-c. bridge for measuring dielectric loss and power factor with great accuracy at very low power factors is described. Some new and interesting conclusions have been drawn from the results and theories formulated to account for the results.

Tuesday Morning

Protection, Control and Bus Construction

9. *Operating Performance of a Petersen Earth Coil-II*, J. M. Oliver and W. W. Eberhardt, Alabama Power Company.

A record of eleven months' operating experience with a Petersen earth coil installed on a 44,000-volt transmission system. A compilation of system troubles is given showing how often the coil functioned correctly or incorrectly. In 109 cases of insulator flashover the coil operated correctly in 94 cases.

10. *Theory of the Auto-Valve Lightning Arrester*, Joseph Slepian, Westinghouse Electric & Mfg. Company.

A discussion of the advantages of the valve-type arrester for protection of high-voltage power systems. The theory of the autovalve arrester is given including a discussion of the breakdown potential of very short gaps.

11. *Current-Limiting Reactors with Fire-Proof Insulation on the Conductor*, F. H. Kierstead, General Electric Company.

This paper describes tests made to determine the proper insulation to use to prevent flashovers of current-limiting reactors due to conducting objects accidentally lodged between the turns. The paper describes (a) short-circuit tests to determine the insulation necessary and (b) thermal tests to determine the fire-resisting characteristics of the insulation.

12. *Temperature Rise and Losses in Structural-Steel Members Exposed to the Fields from A-C. Conductors*, O. R. Schurig and H. P. Keuhni, General Electric Company.

Results of an experimental investigation to obtain practical data on the temperature rises and losses in various structural-steel members when exposed to the fields from a-c. conductors. Should be useful to designers in making estimates of temperature rise and avoiding construction in which heavy losses would occur. Data are given which will serve as a basis for designing copper sleeves to mimimize heating and losses in iron members.

13. *Carrying Capacity of Sixty-Cycle Busses for Heavy Currents*, Titus G. LeClair, Commonwealth Edison Company.

This paper describes tests on grouped copper busses carrying very large phase currents. It shows how with very high currents the usual arrangement becomes quite inefficient on account of unequal distribution of current. Special arrangements of bus bars are suggested which have much greater current-carrying capacity. One arrangement shows a three-phase bus which carried 8500 amperes per phase with 30 deg. cent. rise.

14. *Supervisory Systems for Electric Power Apparatus*, Chester Lichtenberg, General Electric Company.

A general survey and description of the various types of supervisory systems for control and indication of remotely located electrical apparatus. The systems described are classed as follows, (1) selector, (2) distributor, (3) audible, (4) code-visual, (5) synchronous-relay-visual and (6) carrier-current. The principles and features of each system are discussed. Also the supervisory system is compared with the better known remote-control system. Telemetering also is covered.

Tuesday Afternoon

Two Parallel Sessions, A and B

(A) Electrical Machinery

15. *Experimental Determination of Losses in Alternators*, Edouard Roth, Societe Alsacienne de Constructions Mecaniques.

This paper presents some studies made to find accurate and simple methods of determining the losses in large electrical machines, particularly alternators. The studies were undertaken because it was felt that the separate-loss method when used for determining the efficiency of large machines does not give correct results.

16. *No-Load Copper Eddy-Current Losses*, Thomas Spooner, Westinghouse Electric & Mfg. Company.

This paper is an attempt to place on a firm theoretical foundation the calculation of no-load copper eddy-current losses. Test results are presented to show that the theoretical formulas developed are correct. Some of the consequences of this analysis are rather unexpected where the frequencies are sufficiently high to produce large skin effect. For instance laminating the copper may increase or decrease the losses depending on conditions.

17. *Mechanical Force Between Electric Circuits*, R. E. Doherty and R. H. Park, General Electric Company.

In this paper a general equation is developed for the mechanical forces exerted by electric circuits containing inductances which are functions both of position and of current. The equation is applicable to circuits involving saturated iron. The results are to be used in investigating the forces in synchronous machines under short-circuit conditions.

18. *Concluding Study of Ventilation of Turbo-Alternators*, C. J. Fechheimer and G. W. Penney, Westinghouse Electric and Mfg. Company.

An investigation by means of models of a method of ventilating turbo-alternators. Test results, the methods of determining the losses and the equations derived are given.

(B) Communication and Sound Reproduction

19. *The Development and Application of Loading of Telephone Circuits*, William Fondiller, Western Electric Company and Thomas Shaw, American Telephone & Telegraph Company.

A review of the art of loading telephone circuits as practised in the United States. Loading is discussed in relation to developments during the last 14 years pertaining to (1) phantom group loading, (2) loading for repeatered circuits, (3) incidental cables in open-wire lines, (4) crosstalk, (5) telegraphy over loaded telephone circuits, (6) loading for exchange-area cables and (7) submarine cables.

20. *Automatic Enciphering and Deciphering Systems.*, G. S. Vernam, American Telephone and Telegraph Company.

This paper describes a printing telegraph cipher system developed during the World War for use of the Signal Corps, U. S. Army. The system is so designed that the messages are in secret form from the time they leave the sender until they are deciphered automatically at the office of the addressee. If copied en route the messages cannot be deciphered by the copier even though he has full knowledge of the method used.

21. *Refraction of Short Radio Waves in the Upper Atmosphere*, W. R. G. Baker and C. W. Rice, both of General Electric Company.

Estimation of the most suitable wave lengths for night or day communication between any two points is made possible by the theory and calculations proposed in this paper. The paper shows first how the striking phenomena of short-wave radio transmission (below 60 meters) can be quantitatively accounted for by a simple electron-refraction theory. The paths taken by waves from an antenna to distant points on the earth's surface are calculated. Ideal signal-intensity curves are given which show how the transmitted energy is distributed over the earth's surface. Reflection at the surface also is considered.

22. *High-Quality Recording and Reproducing of Music and Speech*, J. P. Maxfield and H. C. Harrison, Bell Telephone Laboratories, Inc.

An analysis of the general problem of recording and reproducing sound with particular reference to the phonograph. A very definite design of mechanical parts is made possible by substituting in the analysis electrical analogs for mechanical parts and functions. The theory of electrical filters is applied to these analogs and is of great assistance in determining the desired mechanical wave-transmission system for high-quality recording and reproduction.

Tuesday Evening

Smoker

Wednesday Morning

Electrical Machinery

23. *Parameters of Heating Curves of Electrical Machinery*, V. Karapetoff, Cornell University.

In this paper it is pointed out that an electrical machine, for thermal purposes cannot be considered as a single body. In a rotating machine the stator consists of two metal bodies between which there may be a temperature difference and the same is true of the rotor; besides there is a mutual heat flow between stator and rotor. In a transformer three separate metal bodies at different temperatures may be distinguished.

24. *Rating of Electrical Machinery as Affected by Altitude*, C. J. Fechheimer, Westinghouse Electric & Mfg. Company.

It is known that an electrical machine carrying a given load becomes hotter at high altitude than it does at sea level. This paper proposes equations to show how the temperature increases with elevation. Also equations are given for the corollary case, namely, to show how the rating must be decreased at high altitude for the same temperature rise as normally occurs at sea level. The paper discusses the rules of the A. I. E. E. Standards on this point.

25. *Motor Band Losses*, Thomas Spooner, Westinghouse Electric & Mfg. Company.

This paper shows that railway-motor band losses are of appreciable magnitude, sometimes large enough to be detrimental to th8 cooling of the motor. Band losses are shown to vary accordine to (a) the 1.7 power of the frequency and (b) the 1.35 to the 1.g power of the induction.

26. *Starting Characteristics of Polyphase Squirrel-Cage Induction Motors and Their Control*, H. M. Norman, Westinghouse Electric & Mfg. Company.

The characteristics of squirrel-cage induction motors during starting, stopping and reversing are discussed in this paper. Equations are given which allow a comparison to be made between loss and time of acceleration. These equations are useful in determining the best value of secondary resistance for a certain application. Short methods are given for determining time of acceleration and moment of inertia of rotors.

WEDNESDAY AFTERNOON

Inspection Trips.

WEDNESDAY EVENING

Dinner-Dance, (Hotel Astor)

THURSDAY MORNING

ELECTROMAGNETISM AND PHYSICS

27. *Calculation of Magnetic Attraction*, Th. Lehmann, Consulting Engineer.

A description of a simple and practical way of surveying and appraising the magnetic force in an air gap by means of the theory of the potential function. The author decomposes the magnetic field into elemental tubes of magnetic force whose envelopes enclose spaces in which the magnetic density is constant.

28. *The Magnetic Hysteresis Curve*, Hans Lippelt, with Thomas E. Murray, Inc.

An analysis of the phenomena of hysteresis introducing the conception of a reactive component and a dissipative component of the counteractive force which acts when magnetic material is subjected to a magnetizing force. Equations and curves are developed which show how these components vary with variations of the magnetizing force.

29. *Properties of the Single Conductor*, Carl Hering, Consulting Electrical Engineer.

In this paper the properties of a unit length of single, straight conductor far removed from all other circuits are investigated in an endeavor to find whether such a unit is a basic, fundamental one on which deductions and a method of mathematical treatment could be based. A constant is deduced for the energy stored by a current in such a unit length, which seems to be one of the most fundamental, basic constants in electrodynamics, from which many useful deductions can be made. This energy corresponds to the $mv^2/2$ of moving masses. It is shown that what might be called "wattless flux" should be recognized, and that "self-inductance" is used in two senses which may sometimes lead to different results.

30. *Heaviside's Proof of His Expansion Theorem*, M. S. Vallarta, Massachusetts Institute of Technology.

Heaviside's proof of his Expansion Theorem found scattered in his "Electrical Papers" is reconstructed in this paper. It is based on his so-called "conjugate theorem" which establishes a relation between any two normal modes of oscillation of a dynamical system. The relations between Heaviside's, Carson's and Wagner's proofs are pointed out.

THURSDAY AFTERNOON

MEASUREMENTS, MACHINERY AND INDUSTRIAL

31. *A New Wave-Shape Factor and Meter*, L. A. Doggett, J. W. Heim and M. W. White, all of Pennsylvania State College.

A meter for determining wave-shape factor is described in this paper. This meter is claimed to have advantages over the method of analysis based on oscillograms. The advantages come under the following headings: (1) cost, (2) portability, (3) ease of experimental procedure (4) rapidity of obtaining results and (5) accuracy and consistency. The meter consists essentially of a star-connected circuit consisting of two voltmeters and a variable condenser.

32. *Practical Application of Vibration Instruments to Rotating Electrical Machines*, J. Ormondroyd, Westinghouse Electric & Mfg. Company.

The possibilities of using vibration instruments in testing rotating electrical apparatus are outlined in this paper. The advantages of vibration-type instruments for certain purposes and an outline of instruments adapted to the various uses are discussed.

33. *Use of High Frequency for Testing Insulation of Rotating Apparatus*, R. E. Ferris and J. L. Rylander, both of Westinghouse Electric and Mfg. Company.

This paper tells of the advantages of using high-frequency voltage for testing the insulation between the turns of coils or windings. By the use of high frequency, high voltages may be applied between turns. This method has been found useful as a shop method for checking defects in material and poor workmanship.

34. *The Cross-Field Theory of Alternating-Current Machines*, H. R. West, General Electric Company.

This paper shows how a general plan of analysis following the cross-field theory may be applied to a-c. motors to obtain simple and accurate numerical methods for routine calculations of performance characteristics. To explain the details and application of the method two examples are worked respectively for a single-phase induction motor and a repulsion motor.

35. *Rating of Heating Elements for Electric Furnaces*, A. D. Keene and G. E. Luke, both of Westinghouse Electric & Mfg. Company.

An experimental study of the effective heat produced by various arrangements of resistor heating elements such as used in electric ovens and furnaces. The effects of spacing, resistor shape, shielding, radiation and reflection are studied. The resultant data obtained should be useful in designing ovens and furnaces.

THURSDAY EVENING

Address by prominent speaker.

Five Regional Meetings Planned For Coming Year

The Regional Meeting idea has worked out so successfully in the Institute that three, and possibly five, of these meetings will be held during the year 1926. Meetings will be held in Cleveland, Niagara Falls, and Madison, Wis., during the first half of the year; and possibly in New York and Kansas City during the latter half.

Very fine programs are contemplated for all these meetings and technical papers of the highest quality will be presented. Authors of high-grade papers are realizing that their papers will be well received and ably discussed at the regional meetings. There are two advantages to presenting a paper at a regional meeting. The first results from the fact that papers are selected which will be of particular interest in the locality where the meeting is held, and therefore the audience will be responsive. The second advantage is that ample time is allowed for discussion. These papers are given the same treatment and publication rights as are papers for the so-called national conventions.

The plans for the contemplated meetings are given in the following paragraphs.

Cleveland Regional Meeting March 18 and 19

Sectionalized electrical drive and electrical refrigeration will be the principal technical topics discussed at the regional meeting which will be held under the Second District of the Institute at Cleveland on March 18 and 19. The social side of the meeting has been well planned and trips of inspection also will be made. The Hotel Cleveland will be headquarters.

The technical papers on sectionalized electrical drive will deal specifically with application to paper-making machines, but on account of the great possibilities of applying synchronized drives in other industries it is felt that these papers will attract to the meeting many engineers connected with rubber mills, textile

mills, wire mills, coal-handling, conveying, automobile production, etc. Three papers on this subject will be presented on March 18 by representatives of the three manufacturers who make equipment for this purpose. The authors will be H. W. Rogers of the General Electric Company, S. A. Staege of the Westinghouse Electric and Manufacturing Company, and R. N. Norris of the Harland Engineering Company.

A paper on Electrical Refrigeration will be presented on March 19 by C. F. Kettering, president of the General Motors Engineering Corporation. This will be followed by an address by Dr. Farley Osgood, Past-President of the Institute on The Human Side of Engineering.

Ample time for very full discussion will be allowed on all the papers presented at this meeting as the committee in charge has arranged the program with this object particularly in view.

A dinner will be held on the first evening at which two addresses will be delivered. These will probably be given by City Manager Hopkins of Cleveland and John Stanley, president of the Cleveland Railway. A number of inspection trips will be available, the main trip being one on the second evening to the Nela Park laboratories.

Arrangements for the meeting are being made by a competent general committee which is as follows: Chairman, A. M. MacCutcheon; Secretary, C. S. Ripley; A. G. Pierce, Vice-President of District No. 2; C. L. Dows, Ralph Higgins, A. F. E. Horn and Nathan Shute.

Madison Meeting in May

Rural electrification, interconnection between power systems, cooperative research relations between colleges and industries, and underground distribution developments will be featured on the program of the regional meeting to be held in Madison, Wis., early in May. Various other subjects also will be covered. This will probably be a two-day meeting. The officers of District No. 5 are progressing with further details of the plans.

Niagara Falls Meeting, May 26-28

A three-day meeting with a wide variety of technical topics will be held by District No. 1 at Niagara Falls, N. Y., May 26, 27 and 28. A number of important engineering subjects will be covered and a full program of social and entertainment features is contemplated.

The technical subjects will include methods of dielectric-loss measurements, transmission, power plants and a number of other topics.

Plans are being made for a special illumination of the Falls, a trip down the Gorge, visits to power plants, a dinner and entertaining addresses of general interest. Further details will be published in later issues.

Future Section Meetings

Boston

Latest Design and Practise in Power Plants, by Vern E. Alden, Consolidated Gas, Elec. Lt. & Pr. Co. Lorimer Hall, Tremont Temple. Joint meeting with A. S. M. E. January 14.

High-Tension Cable Testing, by F. M. Farmer, Electrical Testing Laboratories. Meeting to be held in the new 750,000-volt testing laboratory of the Simplex Wire & Cable Co., Boston, Mass. February 19.

Connecticut

Maintenance of Industrial Equipment. Hartford. January 19.

High-Voltage. New Haven. January 29.

Patents. Stamford. February 9.

Lehigh Valley

Research of Today, the Engineering of Tomorrow, by E. B. Craft, Bell Laboratories, Inc. Joint meeting with Engineers' Club, Lehigh University Branch and Lafayette College Branch. Easton, Pa. January 20.

St. Louis

Long-Distance Cable Communication for St. Louis, by H. H. Nance, American Tel. & Tel. Co. January 20.

New York

The next meeting of the New York Section of the A. I. E. E. will be held at 8:15 p.m., Friday, January 29, 1926, Auditorium, Engineering Societies Building, 33 West 39th Street, New York, and will be devoted to a subject of inherent interest to every engineer,—in fact to the general public itself,—"The Trend of the Electric Light and Power Industry." The meeting will be based on an analysis and discussion of the prize winning papers in the essay contest, conducted last Spring by Bonbright and Company.

The Meetings and Papers Committee has been successful in obtaining several very prominent speakers:

Robert M. Davis, Statistical Editor of the *Electrical World* and second prize winner in the contest will give a statistical analysis or survey of the field, including an analysis of the 1925 operating figures which will then be available.

H. P. Liversidge, Vice-President of the Philadelphia Electric Company, will discuss the engineering possibilities and probabilities in the industry's development.

John F. Gilchrist, Vice-President of the Commonwealth Edison Company, will discuss the commercial policies and probable developments.

H. V. Bozell, of Bonbright & Company, will cover the financial questions.

Other speakers of prominence will probably take part in the general discussion.

Directly preceding the meeting a second get-together dinner will be held at the Fraternity Club, and as accommodations are limited, members of the Section should make an early return of the dinner reservation cards which will accompany the regular notice.

New York Electrical Society to Discuss Long Distance Broadcasting

At a meeting of the New York Electrical Society to be held in the Auditorium, Engineering Societies Building, 33 West 39th St., New York, N. Y., at 8.15 p. m. on the evening of Wednesday, January 6th, 1926, Mr. S. M. Kintner, Manager of Research Dept., Westingthouse Elec. & Mfg. Co., will give an instructive talk on "Long Distance Radio Broadcasting." Short wave length broadcasting is in a very active stage of development and Mr. Kintner is particularly qualified to describe the most recent accomplishments. The talk will be accompanied by some unusually interesting and unique experiments and demonstrations. All interested in this meeting are cordially invited to be present as the guests of the Society.

Annual Meeting of American Society of Civil Engineers

The American Society of Civil Engineers will hold its seventy-third Annual Meeting beginning January 20, 1926, in the Engineering Societies Building, New York, N. Y. The general arrangement so popular in the past will be followed, with business sessions and honorary awards Wednesday morning; reports of the Society's committees Wednesday afternoon; meeting of the Technical Division throughout Thursday and an all-day excursion on Friday, the 22nd.

Beside the awards of Society prizes and medals, the Wednesday morning session will embrace the conferring of two honorary memberships—one upon William Barclay Parsons and the other upon Arthur N. Talbot.

A wide range of subjects will be considered in the technical sessions of Thursday, many of them of general as well as national importance.

Edison Medal Awarded Professor Harris J. Ryan

The Edison Medal for the year 1925 has been awarded by the Edison Medal Committee of the Institute to Dr. Harris J. Ryan, Professor of Electrical Engineering, Stanford University, California, "for his contributions to the science and the art of high-tension transmission of power."

Dr. Ryan was born in Powells Valley,, Pa., January 8, 1866 He studied at Baltimore City College 1879 to 1880; Lebannon. Valley 1880 to 1882, and received the degree of M. E. in Electrical Engineering from Cornell in 1887. In 1888 he became a member of the Western Engineering Company at Lincoln, Nebraska, and in 1889 Instructor in charge of the electrical machinery laboratory at Cornell. From 1890 to 1895 he served as Assistant Professor of electrical engineering in provisional charge of the department and from 1895 to 1905 was Professor in charge of the department of electrical engineering. In 1905 he accepted the same position at Stanford University which he holds today. In 1909 Professor Ryan became consulting engineer for the Los Angeles Aqueduct Power Development. During the war as a member of the Pacific Coast Section of the Submarine Group of the National Research Council he carried on valuable work and in 1918 and 1919 was in charge for the Research Council Supersonics Laboratory at Pasadena.

Harris J. Ryan

In the Chicago Exposition of 1893 Professor Ryan was a member of the Jury of Awards of the Department of Electricity and in 1904 was a delegate to the International Electrical Congress, St. Louis Exposition. He is a Fellow of the American Association for the Advancement of Science, member of the American Electrochemical Society, Institute of Radio Engineers, Society for Promotion of Engineering Education, American Physical Society and National Academy of Science. In 1887 he was elected an Associate of the A. I. E. E.; in 1895 was transferred to Member and in 1923 became a Fellow. He was a Director of the Institute from 1893 to 1896; Vice-President, 1896 to 1898; Honorary Vice-President representing the Institute at the Panama-Pacific International Exposition, San Francisco, 1915; President, 1923-24; and has served on the Edison Medal, Meetings and Papers, Electrophysics, Transmission and Distribution and Research Committees.

During Professor Ryan's twenty years at Stanford, he has been a pioneering leader in high-voltage transmission, upon the development of which largely depends the future growth of the Pacific Coast region. About three years ago the first 220,000-volt power lines were successfully put into commission by California companies, and Professor Ryan cooperated with the engineers in finding ways to cope with the insulator problems encountered, and it is on the solution of similar problems that his genius in the research field is expected to continue an outstanding advantage to science.

The Edison Medal was founded by the Edison Medal Association, composed of associates and friends of Mr. Thomas A. Edison, and is awarded annually by a committee consisting of twenty-four members of the American Institute of Electrical Engineers for "meritorious achievement in electrical science, electrical engineering, or the electrical arts."

The medal has previously been awarded Elihu Thomson, 1909; Frank J. Sprague 1910; George Westinghouse, 1911; William Stanley, 1912; Charles F. Brush, 1913; Alexander Graham Bell, 1914; Nikola Tesla, 1916; John J. Carty, 1917; Benjamin G. Lamme, 918; W. L. R. Emmet, 11919; Michael I. Pupin, 1920; Cummings C. Chesney, 1921; Robert A. Millikan, 1922; John W. Lieb, 1923; John White Howell, 1924.

First Convention of Radio Engineers

A convention of the Radio Engineers will be held in New York, January 18-19, 1926, when the Institute of Radio Engineers holds its Annual Meeting in the Engineering Societies Building, 33 West 39th Street. Important technical papers will be presented and discussed by engineers prominent in the profession; there will be organized trips of inspection to large radio factories and broadcasting stations, and the convention will close with a banquet at which many of the foremost radio engineers and executives of the country will deliver addresses on up-to-the-minute radio topics.

It is desired that every one identified with the Institute of Radio Engineers will attend one or more of the sessions, and guests are welcome. Chairman of the Convention Committee is R. H. Marriott.

A. I. E. E. Directors Meeting

The regular meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Friday, December 11, 1925.

Officers present were: President M. I. Pupin, New York; Past-President Farley Osgood, Newark, N. J.; Vice-Presidents Harold B. Smith, Worcester, Mass.; A. G. Pierce, Cleveland; Managers H. M. Hobart, Schenectady; G. L. Knight, Brooklyn, N. Y.; H. P. Charlesworth, N. Y.; John B. Whitehead, Baltimore; E. B. Merriam, Schenectady; H. A. Kidder, New York; National Treasurer George A. Hamilton, Elizabeth, N. J., and

National Secretary F. L. Hutchinson, New York; also by invitation: Messrs. A. W. Berresford, J. Franklin Meyer and John B. Taylor.

The minutes of the meeting of the Directors held October 14, 1925, were approved.

Reports of meetings of the Board of Examiners held November 16, and December 7, 1925, were presented and the actions taken at those meetings were approved. Upon the recommendation of the Board of Examiners, the following actions were taken on pending applications: 764 Students were ordered enrolled; 84 applicants were elected to the grade of Associate; 7 applicants were elected to the grade of Member; 1 applicant was transferred to the grade of Fellow; 37 applicants were transferred to the grade of Member.

The Board ratified the approval by the Finance Committee of monthly bills amounting to $18,391.51.

A request from the Executive Committee of the Great Lakes Geographical District, for authority to hold a regional meeting at Madison, Wisconsin, early in May 1926, was approved.

The organization of a Section at Sharon, Pa. was authorized in accordance with a petition from members in Sharon and vicinity.

The organization of a Student Branch at Stevens Institute of Technology, Hoboken, N. J., was authorized.

The Edison Medal Committee reported that the medal for the year 1925, has been awarded to Professor Harris J. Ryan, of Stanford University, Cal., "for his contributions to the science and the art of high-tension transmission of power."

Upon request of the Committee on Education, an appropriation of $600 was made, to apply to the cost of cooperating with the Society for the Promotion of Engineering Education, in an investigation relating to electrical engineering courses in colleges.

Mr. G. L. Knight was appointed a representative of the Institute, upon the Board of Trustees of the United Engineering Society, to succeed H. A. Lardner, whose term will expire in January and who is not eligible for re-appointment.

Professor W. I. Slichter was appointed to succeed himself as a Member of the Library Board of the United Engineering Society, for three years, beginning January 1, 1926.

Messrs. A. G. Pierce, of Cleveland and E. C. Stone, of Pittsburgh, were appointed Alternates, upon the Assembly of the American Engineering Council.

The report of Dr. A. E. Kennelly, who represented the Institute at the Fourth National Radio Conference, Washington, November 9-11, 1925, was presented and accepted with a vote of appreciation to Dr. Kennelly for his services.

Other matters of importance were discussed, reference to which may be found in this and future issues of the JOURNAL.

Standards of the A. I. E. E.

At the meeting of the Board of Directors held December 11, 1925, the following Sections of Standards, as recommended by the Standards Committee, were adopted as Institute Standards.

No. 9—Standards for Induction Motors and Induction Machines in General.

No. 30—Standards for Wires and Cables.

No. 9 was referred to the Sectional Committee on Rating of Electrical Machinery, for consideration and report to the sponsor. No. 30 was referred to the Sectional Committee on Insulated Wires and Cables, for consideration and report to the sponsor, and then to be referred to the American Engineering Standards Committee for approval as an American Standard.

The following three Sections of the A. I. E. E. Standards were referred to the Sectional Committee on Rating of Electrical Machinery.

No. 5—Standards for Direct-Current Generators and Motors and Direct-Current Commutator Machines in General.

No. 7—Standards for Alternators, Synchronous Motors and Synchronous Machines in General.

No. 10—Standards for Direct-Current and Alternating-Current Fractional Horse Power Motors.

The following resolutions were adopted:

RESOLVED

THAT in support of the plans and purposes of the A. E. S. C. in establishing American Standards, and recognizing the value and necessity of cooperative procedure in the field of electrical standardization, the Board of Directors of the American Institute of Electrical Engineers recommends to the A. E. S. C. that the A. E. S. C. set up an Electrical Advisory Committee of the A. E. S. C. constituted of representatives of at least the major interested groups, to advise the Main Committee on all questions relating to Electrical standards and to serve as a general coordinating committee in the electrical field within the scope of the Constitution, By-Laws and Rules of Procedure of the A. E. S. C.

RESOLVED FURTHER

THAT it is recommended that this Advisory Committee should have such constitution and functions as to be sufficiently elastic to permit the appointment of Special Committees of particularly qualified experts to pass upon specific questions in case any interested parties so requesting should submit to the A. E. S. C. reasonable evidence of the desirability of such action.

Corrections in Standards Pamphlets

Section 1. General Principles Upon Which Temperature Limits are Based in the Rating of Electrical Machinery and Apparatus.

In the reprint (September 1925) of Section 1 of the A. I. E. E. Standards the following fundamental statement should appear just below the title on page 5:

"THESE ARE NOT RULES FOR RATING OR TESTING"

"The limits of temperature and temperature rise given in the pamphlet are not limits for the rating or testing of electrical machinery. The pamphlet deals with the general considerations upon which rating limits are based. It is the introductory chapter to the Standards of the A. I. E. E."

Attention is also called to the corrections as noted on page 1359 of the December JOURNAL. Correct copies of both Sections 1 and 10 can be obtained by returning the incomplete pamphlets to H. E. Farrer, Secretary, Standards Committee, A. I. E. E., 33 West 39th St., New York, N. Y.

American Roadbuilders' Association in Convention January 11-14.

The Annual Convention and Road Show of the American Road Builders' Association will be held in Chicago, January 11-15, 1926. Sessions will be held for the discussion of varying problems in connection with traffic regulation, highway design and construction, with an innovation this year of a division of these meetings into two sections—one for the investigation of traffic and engineering problems contingent to the cause, and the other for points of interest on the side of construction. Men nationally representative for each subject on the program will address the meetings and these addresses will be followed by open, general discussion.

Dr. Parke Rexford Kolbe New President of Polytechnic Institute

An event of interest to engineers and chemists generally will take place at the Academy of Music, Brooklyn, N. Y., on January 13th, 1926, when Doctor Parke Rexford Kolbe will be installed as the new president of the Polytechnic Institute. Doctor Charles Alexander Richmond, president of Union College, will deliver the principal address of the evening; the presentation of the charter, seal and keys will be made by Charles E. Potts, of

the class of 1892, now chairman of the Board of Trustees of the Polytechnic Institute. Other speakers of the evening will be Doctor William H. Nichols, chairman of the Board of the General Chemical Company, and for many years chairman of the Corporation of the Polytechnic Institute; Doctor George S. Collins, senior member of the faculty, and Bancroft Gherardi, chief engineer of the American Telephone and Telegraph Company. Official delegates from colleges, universities and societies have been invited to attend and acceptances received indicate an attendance of a noteworthy number of prominent men from all parts of the country; among them Robert Lincoln Kelley, executive secretary of the Association of American Colleges; George B. Pegram, president of the Society for the Promotion of Engineering Education; W. E. Wickenden, director of Investigation for the Society for the Promotion of Engineering Education; H. Foster Bain, secretary of the American Institute of Mining and Metallurgical Engineers; Robert Ridgway, American Society of Civil Engineers; Elmer E. Brown, Chancellor, New York University; Charles C. Mierow, president of the Colorado College; General James G. Harbord, Kansas State Agricultural College, Col. R. C. Langdon, West Point; Arthur M. Greene, Jr., Engineering Foundation; Palmer C. Ricketts, Rensselaer Polytechnic Institute, and Allen Hazen, University of New Hampshire. A reception for the official delegates will be held at the conclusion of the academic exercises.

ENGINEERING FOUNDATION

PROFESSOR MARX SUCCEEDS PROFESSOR DERLETH, Jr.

Charles David Marx, professor emeritus of civil engineering, Leland Stanford, Jr., University, has been elected chairman of the Engineering Foundation Committee in charge of the Arch Dam Investigation. He succeeds Professor Derleth, Jr., of the University of California, who relinquishes the chairmanship because of ill health, but continues a member of the working committee.

The Southern California Edison Company is furnishing the services of its chief construction engineer, H. W. Dennis to be in charge of the building of the test dam, and also the services of other members of its organization essential to the accomplishment of this undertaking. Use of the property for the erection of the dam is contributed by the U. S. Department of Agriculture: The Portland Cement Association is also cooperating and Doctor J. A. Mathews, vice-president and metallurgist of the Crucible Steel Company of America is producing special metal for some of the instruments.

The Engineering Foundation contributes funds and services for the general purpose of the Committee, but unfortunately its resources will not yet permit it to do more. It invites all others interested to cooperate in providing the remainder of the $100,000 necessary to the completion of the dam.

AMERICAN ENGINEERING COUNCIL

AN APPEAL TO AID BILL FOR PROVIDING ADEQUATE SALARIES FOR FEDERAL JUDGES

BY EDWIN J. PRINDLE,
Chairman, Patents Committee

Americans having to do with engineering, science or the industries are pretty generally aware of the tremendous importance of keeping our patent system operating in a helpful and efficient manner. They realize that that system has been of primary importance in enabling our country to attain the foremost position among the nations in inventing, manufacturing and agriculture. When the Patent Office was going to pieces because of salaries insufficient to induce trained Patent Office Examiners to stay in the service, after a long and arduous campaign, the technical and scientific men and the manufacturers succeeded in sufficiently raising the Patent Office salaries to stem the tide of resignations, with the result that the Patent Office was saved from disintegration and has now made substantial progress toward an efficient condition.

But the granting of patents is only one branch of the operation of the patent system. The other branch is the adjudication of patents and their enforcement in proper cases. This latter function is performed exclusively by the federal courts and the efficient operation of those courts is of as much importance to the patent system as that of the Patent Office. The rise in the cost of living, and the depreciation of the purchasing power of the dollar have placed those in courts in a position where their efficiency is being impaired by causing many excellent judges to resign and by disturbing that peace of mind without which the best work is not likely to be done. Many of the judges are restive and waiting to see whether relief will not be given them, feeling that they will be forced to leave the bench if the present condition continues. Distress of the judges is particularly keen in the larger cities where the cost of living is highest. Here also it is more unjust that they should be asked to work for totally inadequate salaries because the compensation which they could receive in the private practise of law is correspondingly greater. The federal courts have jurisdiction over a wide variety of subjects—much wider than that of the courts of any of the States—so that the position is one of large responsibility, and requiring a high order of ability. Yet their salaries are so low that they are unable to live as befitting their station and the high dignity of their office, and to educate their children. They may not practise law, and have practically no opportunities for earning, outside of their salaries.

These conditions are probably more important to the welfare of our patent system than to any other branch of the law, because almost without exception, the federal judges when appointed, have had no contact whatever with patent law. It takes years of education and experience in trying and listening to the argument, and in deciding patent cases, to make a competent patent judge under these circumstances. When a federal judge who is efficient in patent law resigns, the process of education has to be gone through with by his successor, and the result necessarily is in such cases that the average ability brought to the decision of patent cases over a series of years is low. A few unwise decisions would cost not only the parties, but the country, many times the difference between present salaries and adequate ones.

The United States district judges receive but $7500 per annum and United States circuit judges only $8500. Comparison with the salaries paid in the State courts shows the gross unfairness of these salaries.

In New York City the Supreme Court judges receive $17,500, and the question is being considered of raising that salary. The judges of the New York Court of Appeals in Albany receive $13,750.

In New Jersey the judges of the Supreme Court receive $18,000.
In Pennsylvania they receive $17,500.
In Illinois they receive $15,000.
In Massachusetts they receive $12,000.
In Michigan they receive $10,000.

A bill having the approval of the federal judges has been introduced into Congress, known as the Reed Bill, which provides salaries for the circuit judges of $15,000 for the Second Circuit, comprising New York and Vermont; $14,000. for the next most populous circuits—Third, Seventh, Eighth and Ninth; and $13,000 for the remaining of the nine circuits.

The Bill provides salaries for the United States District judges of $10,000 with the provision that if the population in a district exceeds 2,000,000 the salaries shall be increased $500 for each 100,000 population in excess of that sum up to within $1000

of the circuit judges' salary. If the differential in favor of the salaries in the more populous districts should not be enacted, then the salaries for the district judges in general should be correspondingly raised.

While our federal judicial system is one of the three great branches of our government and is co-equal in importance with the legislature and the executive, yet its cost is truly insignificant. There are only 191 federal judges, and the cost per capita is now but one and one-half cents.

No matter how conscientious a judge may be, it is impossible for him to have as high an average of clear, penetrating thought in deciding the many intricate and important questions which come before him if his living and that of his family are inadequately provided for, as if his mind is reasonably free from financial care. The loss to the public through avoidable mistakes of failure to think clear through a problem under these conditions, must be vastly greater than the cost of proper salaries.

As Ex-Judge Edwin L. Garvin of Brooklyn has said:

> "The present salaries paid to United States judges are a disgrace to the American people."

Judge Garvin has just left the Federal Bench, being forced to do so by inability to live on his salary and the absolute impossibility of giving a college education to either of his children. Many of the federal judges are eking out their salaries by using the savings which they had provided for their old age. The American Engineering Council has adopted vigorous resolutions favoring the increase of the federal judiciary salaries, and last winter appeared, by Mr. L. W. Wallace, its Executive Secretary, the Chairman of its Patents Committee, and other representatives, before the Committees of Congress in favor of bills for that purpose. These efforts will be continued and reinforced at the present session of Congress.

Fair play and simple justice should make every American citizen interested in correcting this unjust and unwise condition. Every man and concern who is at all interested in patents and in preserving our patent system in an efficient condition should express himself to his Senator and Representatives as being strongly in favor of immediately passing the Reed Bill or some other bill for raising the salaries at least as high as that bill.

Let us be as effective in aiding the federal judges as we were in aiding the Patent Office. That can be done if every man will do his duty.

Industrial Cooperation With the War Department

Hearty endorsement of the War Department in its program for industrial preparedness and insurance against war was represented by the large audience which gathered in the Engineering Societies Building, New York, on the evening of December 4, at a meeting held under the auspices of the New York Sections of the A. I. E. E., A. S. C. E., A. I. M. E., A. S. M. E., American Chemical Society and Society of Automotive Engineers, and the Army Ordnance Association. Honorable Elbert H. Gary presided and the speakers of the evening were Dwight F. Davis, Secretary of War; Hanford MacNider, Assistant Secretary of War; General James G. Harbord, president of the Radio Corporation of America, and Major-General Charles P. Summerall, Commander of the Second Corps Area, U. S. Army. A telegram of commendation from President Coolidge also was read. Prior to the addresses, the colors of the 24th Regiment of Engineers were transferred, by an impressive ceremony, to the custody of the United Engineering Societies.

Secretary Davis first spoke of the many constructive peacetime accomplishments of the Army, including its activities in standardization, communication, navigation, power development, medicine, agriculture, mail, merchandising and aviation.

He then outlined the plans and the necessities for industrial preparedness for national defense. He said, in part, that the saving of time in swift and effective mobilization is the essence of all plans. Industrial preparedness means that demands of finance, power, labor, transportation and materials be intelligently analyzed and properly coordinated, that all resources may be marshalled against aggression. The combination of a weak and wealthy nation has never existed for any length of time. If present plans can render America safe for peace for one generation only they will accomplish more than any other plans in our history.

Two pictures of industry stand out in the planning: The one is the picture of industry as it operates in time of peace; the other, the picture as it looks in war. Industrial preparedness has as its purpose the planning of the transition from one picture to the other, with a minimum of dislocation and confusion both before and after war. Competent bodies have studied and are studying the general problems, with the cooperation of business and industrial concerns and of individuals, and courses of action are being formulated.

In general industrial preparedness is the contribution of business to the national peace. It is preparedness against war, not for war. But if war comes it will be a potent factor in winning peace through victory. Equality of obligation, mutuality of responsibility, the common defense of all by all is the democratic doctrine of a free republic. This is the spirit of industrial preparedness.

Assistant-Secretary MacNider emphasized the fact that for each combat soldier there should be seventeen people backing him up with material. With the help of experts and business executives plans have been formulated for swift mobilization. The supply organization must be built so that it can in a moment be stretched to a hundred times its peace-time size and function effectively. The nation's best insurance against war is not a great army but an expert nucleous.

General Harbord emphasized the need of sustaining interest and support for the work of national defense of which industrial preparedness is one part. To bring out the advantage of preparedness, he stated that if the present plan and organization had been in effect prior to the World War, besides greatly decreasing our losses in killed and wounded, for every hour by which the war was shortened one million dollars would have been saved.

Major-General Summerall, in the name of the Army, acknowledged all that industry is doing for the welfare of the military establishment and the country, and said that these efforts hearten and encourage that establishment beyond measure.

ADDRESS OF W. L. SAUNDERS, ACCEPTING THE 24TH ENGINEERS COLORS

Engineering Auditorium, December 4, 1925

Colonel Whitlock and men of the 24th Engineers:

On behalf of the Trustees of United Engineering Society I accept the custody of these colors of the 24th Engineers. They shall be carefully installed and exhibited in the halls of this building, there to remain as a permanent memorial.

Yours was the first regiment of its kind to be organized in the Army of the United States. Never before had the value and aid of the engineers in war been so fully recognized. You built and maintained shops, cement block plants, railways, pumping stations, lighting plants, buildings, hospitals, schools, camps, stables and many other things so important in modern warfare. To the men in the trenches you were what the laboratory is to the chemist. Through such work as you did the world war was brought to an end.

And as future generations look upon these colors, they shall see in them not a cold monument of stone raised to a gallant warrier, whose example one might seek to follow, but a living reminder that strength in war is no longer a human, but a material thing; that through machinery, industry and engineering a nation fully prepared in peace is likewise prepared for and insured against war.

Fuel and Power Meeting Held in Boston

Power problems in industrial plants were discussed at a meeting held in Boston, December 10 and 11, by the Affiliated Technical Societies of Boston of which the A. I. E. E. Section is a member. The papers presented were *Sources and Utilization of Coal*, by F. H. Daniels, Sanford-Riley Stoker Company; *Supply and Utilization of Fuel Oil*, by E. H. Peabody, Peabody Engineering Corp.; *Diesel Engines for New England Power Plants*, by J. F. Hecking, Worthington Pump and Machinery Corp.; *Possibilities of Obtaining Power from Public-Service Corporations*, by L. R. Nash, Stone & Webster, Inc.; *Power for Textile Mills*, by C. T. Main, Consulting Engineer; *Power for the Paper Industry*, by J. A. Warren, S. D. Warren Company; *The Utilization of Power in the Typical New England Plant*, by K. D. Hamilton, Geo. E. Keith Company; *The Advantages and Disadvantages of High-Pressure Steam in Industrial Plants*, by Joseph Pope, Stone & Webster, Inc.; *Utilization of Extraction Steam*, by E. A. Dickinson, General Electric Company; *The Supply of Industrial Power*, by W. H. Larkin, Jr., U.S. Rubber Company; *The Coal Situation*, by E. C. Hultman, Chairman of Special Commission (Mass.) on the Necessaries of Life; *Household Heating*, by H. R. Linn, American Radiator Company.

Sterling Fellowship for Research at Yale

The Sterling Fellowship has been established by a gift of one million dollars from the John W. Sterling Estate, "to stimulate scholarship and advanced research in fields of knowledge." While a Yale University fellowship, this is open to all approved colleges and universities both here and abroad,—men and women —whether graduate students, instructors or professors who desire to carry on studies and research under the direction of the Graduate Faculty of Yale University in affiliation therewith. Applications should be addressed to the Dean of the Graduate School, Yale University, New Haven, Connecticut, on blanks supplied by him. Junior prior to March 1 and Senior Fellowships by April 1.

Penn State Branch Holds Electrical Show

On November 7, the annual Alumni Homecoming Day, the Student Branch at the Pennsylvania State College presented an electrical show in the laboratories of the two Electrical Engineering Buildings. The exhibits which were designed and prepared by the members of the Branch proved of great interest to the thousands who visited the show.

The exhibits, of an educational nature, showed the work carried out in the Electrical Engineering Department of the College. Other exhibits traced the historical development of common electrical devices. Special lighting exhibits were featured at the night session. Numerous trick features constituted a less serious part of the show.

PERSONAL MENTION

G. W. Quentin has resigned from the American Blower Company in Pittsburgh to accept the position of promotion manager for the *Electrical World*.

F. L. Gilman has been elected Treasurer of the Western Electric Company to take effect January 1, 1926, and thereafter will be located at 195 Broadway.

Morris Keiser, formerly with the National Bureau of Standards, has joined the Research Department of the Marland Refining Company as Associate Electrical Engineer.

Harold J. McCreary, Inspection Methods Engineer of the Western Electric Company, has accepted a position as research engineer with the Automatic Electric Company of Chicago.

James R. Cravath, President of the Pioneer Electric Company of Richmond, Calif., has opened an office in the Call Building, San Francisco, as a consulting electrical and illuminating engineer.

Harry A. Yoe has resigned from the engineering department of the New York Central Railroad where he has been employed for ten years and has entered the firm of Schultze & Weaver of New York City.

Clifford G. Hillier, formerly manager of the Merchandising Sales Department of the Westinghouse Electric & Manufacturing Company, in their Boston office, has been appointed manager of the Receiver Section of the Radio Department of that Company, with headquarters in New York City.

Dr. E. R. Berry, assistant director of the Thomson Research Laboratory of the General Electric Company of Lynn, Mass., has been awarded the Grasselli Medal by the American Section of the Society of Chemical Industry, in honor of the paper presented by him describing a new achievement in applied chemistry.

Samuel W. Beach, Chief Radioman, U. S. S. Nevada, has recently written a book entitled, "The Great Cruise of 1925"—a history of the trip made by the United States Fleet to Australia, New Zealand and South Sea ports. It also contains speeches made by the Premiers and Governors-General of Australia and New Zealand upon the occasion of the fleet's visit to their respective countries.

Addresses Wanted

A list of names of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—Ezra Adelsberger, 1912 Cold Spring Ave., Milwaukee, Wis.
2.—F. E. Bell, U. G. I. Contracting Co., Box 371, Sioux City, Iowa.
3.—Geo. B. Coleman, P. O. Box 322, Dayton, Ohio.
4.—T. L. Davenport, 2530 May St., Cincinnati, Ohio.
5.—George E. Haines, 3538 W. Monroe St., Chicago, Ill.
6.—S. Larios, 143 Fourth St., Milwaukee, Wis.
7.—Willis E. Osborne, 312 West 4th St., Erie, Pa.
8.—Mary Shimanovsky, 24 Mt. Morris Park W, New York, N. Y.

Obituary

George I. Brown, an Associate of the Institute since 1908, died on November 1st, 1925. Mr. Brown was a Canadian by birth and received his education under private tutoring and at the University of Toronto, being employed by the Canadian Government during the years 1879 to 1892. Mr. Brown resided in this country for many years, in 1915 opening an office as consulting engineer in Red Bank, N. J.

David C. Rankin, Managing Director of the Commonwealth Power Equipment Company of Melbourne, Australia, died in that city after an illness of two years. Mr. Rankin was a native of Melbourne, being a graduate of Melbourne University, and coming to this country in 1919. He was in the employ of the Guarantee Battery Company of San Francisco as automotive instructor and the Ballantine Electrical Company of Chicago as plant superintendent and general manager, returning to Australia in July, 1923.

Allen A. Tirrell, inventor and consulting engineer of the

Westinghouse Electric & Manufacturing Company died recently. Mr. Tirrell was the inventor of the voltage regulator which bears his name, being employed for some years by the General Electric Company as a designing engineer—later going into business for himself as mechanical and electrical engineer in Pittsburgh.

George Harry Wirth, Associate of the Institute for the past five years, died at his home in Collingdale, Pennsylvania on November 6th. Mr. Wirth received his engineering education at Drexel Institute in Philadelphia; during the World War he served as a commissioned pilot instructor in the air Service of the United States Army. He was afterwards in the employ of Stone & Webster, in Philadelphia, later with the Right and Left Tool Holder Company and with the Edw. G. Budd Manufacturing Company as operator in charge of High Voltage Substations.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES (Nov. 1-30, 1925)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

DYNAMIK, 2; DYNAMIK VON KÖRPERSYSTEMEN.

By Wilhelm Müller. Ber. u. Lpz., Walter de Gruyter & Co., 1925. 137 pp., 6 x 4 in., cloth. 1.25 mk.

Devoted to the methods for mathematically investigating the motion of structures composed of rigid elements. An attempt is made to condense the development of the subject as much as possible and to arrange the whole systematically. The analytic methods used are grouped in general around d'Alembert's principle.

ELEKTROMASCHINENBAU.

By P. B. Arthur Linker. Ber., Julius Springer, 1925. 304 pp., diagrs., 9 x 6 in., boards. 24-gm.

A textbook on the design of continuous-current dynamos and motors, transformers, induction motors, synchronous dynamos and motors, converters and alternating-current commutator motors. The book follows the course given in the Hannover Technical High School.

The author shows how the design of electrical machinery may be based on the intelligent use of the elements and basic laws of theoretical electricity, and how it may be used also to deepen by use the student's knowledge of theory. At the same time, many devices to lessen the purely clerical items of design are shown.

FOUNDATIONS OF BRIDGES AND BUILDINGS.

By Henry S. Jacoby and Roland P. Davis. N. Y., McGraw-Hill Book Co., 1925. 665 pp., illus., diagrs., 9 x 6 in., cloth. $6.00.

Treats of piles and pile driving, cofferdams, caissons, piers, abutments, spread foundations and underpinning. Intended to present American practice on the entire subject of foundations in a systematic manner. Includes a useful, classified bibliography of selected articles.

The new edition has been revised and amplified.

FOUR-FIGURE MATHEMATICAL TABLES.

By G. W. C. Kaye and T. H. Laby. Lond., & N. Y., Longmans, Green & Co., 1925. 26 pp., 10 x 6 in., paper. $.40.

A convenient collection of the mathematical functions usually tabulated in four-figure tables, printed in clear type. Logarithms, anti-logarithms, reciprocals, squares, natural and logarithmic sines, cosines and tangents, degrees to radians, powers, roots and reciprocals are included.

HISTORY OF ARITHMETIC.

By Louis Charles Karpinski. Chic. & N. Y., Rand McNally & Co., 1925. 200 pp., illus., facsims., 8 x 5 in., cloth. $2.00.

A brief account, intended primarily for teachers of arithmetic in elementary schools. Gives particular attention to the material of arithmetic which is still taught in those schools. It also pays particular attention to early American textbooks and to the popular English treatises from which they were derived. Bibliographies accompany each chapter and there are many illustrations from early books.

INTERMEDIATE LIGHT.

By R. A. Houstoun. Lond. & N. Y., Longmans, Green & Co., 1925, 228 pp., illus., diagrs., 8 x 5 in., cloth. $1.75:

A brief elementary textbook intended for use by students in secondary schools and the first years of college.

MAKING, SHAPING AND TREATING OF STEEL. 4th edition.

By J. M. Camp and C. B. Francis. Pittsburgh, Pa., Carnegie Steel Co., 1925. 1142 pp., illus., diagrs., tables, 8 x 5 in., fabrikoid. $7.50. [Payment should accompany order. Money orders and checks to be made payable to Carnegie Steel Co. Orders and inquiries should be addressed to Carnegie Steel Co., Bureau of Technical Instruction, Carnegie Bldg., Pittsburgh, Pa.]

This book is intended primarily for use as a text-book in the schools conducted by constituent companies of the United States Steel Corporation for employees without a technical education. It is also admirably adapted to the needs of every one, wishing an accurate account of standard practice in the American steel and iron industry.

Beginning with a survey of those principles of physics and chemistry which are useful to the metallurgist, the authors take up refractories, iron ores, fuels, fluxes, describing their varieties, properties and uses. The manufacture of pig iron, wrought iron and steel are then discussed, Section two is devoted to the shaping of steel by rolling and forging. Section three treats of the constitution, heat treatment and composition of steel. Section four describes the manufacture of wire, sheets, pipe and tubes.

No other book approaches this in its fulness of detail on current practise in American iron and steel works. It is a complete account of the industry, from the ore to the semi-finished product, prepared by men in intimate contact with current practice.

MECHANICAL INVESTIGATIONS OF LEONARDO DA VINCI.

By Ivor B. Hart. Chic., Open Court Pub. Co., 1925. 240 pp., illus., facsims., port., 9 x 6 in., cloth. $4.00.

The author's primary purpose was to make a detailed study of the nature and value of Leonardo's contribution to the study of aeronautics, but as the study of flight is linked with that of mechanics, the whole field of his work in mechanics has been surveyed.

After an introductory chapter on the characteristics of

Leonardo's manuscripts, there is a discussion of the state of mechanical science in the fifteenth century, of the scientific influences that bore upon Leonardo and of the sources of information available to him. This is followed by an account of his work in mechanics and as a pioneer of aviation. The book concludes with a complete translation of his Codex on the Flight of Birds and other Matters from the manuscript in the Library of Turin.

MECHANISM OF THE CAR.

By Arthur W. Judge. Lond., Chapman & Hall, 1925. (Motor manuals, v. 3.) 175 pp., illus., 8 x 5 in., cloth. 4s.

A non-technical exposition of the basic principles, illustrated by examples from current automobile practice. Covers the chassis, transmission, gears, etc. While adapted to use by owners and mechanics, it also will interest the engineer.

OIL ENGINE POWER PLANT HANDBOOK.

By Staff of Oil Engine Power. N. Y., Oil Engine Power, 1925. 192 pp., illus., diagrs., 11 x 8 in., fabrikoid. $3.00.

The work is a combination of catalog information on the products of various manufacturers of oil engines and accessories, with a series of articles by various engineers. These articles treat of such matters as lubrication, operation and maintenance, valve-setting, installation and similar topics, and are written from a practical viewpoint.

OSCILLOGRAPHS. . . .

By J. T. Irwin. N. Y., Isaac Pitman & Sons, 1925. 164 pp., illus., diagrs., 7 x 5 in., cloth. $2.25.

After a chapter on the fundamental principles involved, the author describes the various types of oscillographs and the methods of damping. Much space is given to the cathode-ray oscillograph. The book is apparently the first in English devoted to the subject and is, the author remarks, to a great extent original.

PHOTO-ELECTRICITY. . . .

By H. Stanley Allen. 2d edition. Lond. & N. Y., Longmans, Green & Co., 1925. (Monographs on physics). 320 pp., 9 x 6 in., cloth. $6.50.

A very complete exposition of our theoretical knowledge of photo-electric phenomena and of the practical applications of photo-electric cells. The new edition incorporates the results of the investigations during the past decade and includes a valuable bibliography of all the relevant papers published between 1913 and 1924.

PRINCIPLES OF ELECTRIC POWER TRANSMISSION AND DISTRIBUTION.

By L. F. Woodruff. N. Y., John Wiley & Sons, 1925. 340 pp., illus., diagrs., tables, 9 x 6 in., cloth. $4.00.

A work based on instruction given to senior and graduate students at the Massachusetts Institute of Technology. Its aim is to call attention to the fundamental scientific principles involved in power transmission and the methods by which they are made applicable to practical engineering problems; and at the same time to impart as much information as is feasible about present practise in electric power transmission.

PROTEUS, OR THE FUTURE OF INTELLIGENCE.

By Vernon Lee. N. Y., E. P. Dutton & Co., 1925. (To-day and to-morrow series.) 63 pp., 6 x 4 in., cloth. $1.00.

In this very interesting little volume Vernon Lee discusses intelligence; what it is, when it originated, and how it influences us in the realms of art, religion, morals and economics and in our personal lives and outlooks.

THEORY OF MEASUREMENTS.

By Lucius Tuttle and John Satterly. Lond. & N. Y., Longmans, Green & Co., 1925. 333 pp., diagrs., 9 x 6 in., cloth. $4.50.

This textbook is intended for use in connection with courses in physics or mathematics. It emphasizes general considerations of measurement, theory of errors, general methods of procedure, quantitative accuracy, adjustment of observations, and similar topics that are usually merely mentioned in a laboratory manual, but that need laboratory work and drill as much as measurements of individual quantities. It is also adapted for use as a reference book.

The work represents a course given in the University of Toronto.

TREATISE ON THE LAW OF PUBLIC UTILITIES.

By Oscar L. Pond. 3rd edition. Indianapolis, Bobbs-Merrill Co., 1925. 1065 pp., 10 x 7 in., buckram. $10.00.

An endeavor to give a full, impartial exposition of the law of municipal public utilities. The book is based on the decisions of the courts and the various commissions, so that it is authoritative and practical. The new edition contains an extended study of motor vehicle transportation and a chapter on the subject of appeals.

Past Section and Branch Meetings

SECTION MEETINGS

Akron

Frogleg Windings for Multipolar D-C. Generators and Motors, by G. M. Albrecht, Allis Chalmers Co. A dinner preceded the lecture. November 20. Attendance 54.

Boston

Business Meeting. November 23. Attendance 8.

Chicago

Rectifiers, by L. T. Robinson, General Electric Co. Joint with Western Society of Engineers. November 23. Attendance 260.

Cincinnati

Transmission Problems, by C. L. Fortescue, Westinghouse Elec. & Mfg. Co. An illustrated lecture on the "Klydonograph" was also given. November 10. Attendance 142.

Connecticut

Distribution at Increased Voltages, by J. E. King, Connecticut Light and Power Co. December 9. Attendance 125.

Cleveland

Inspection trip to the plant of the Otis Steel Company. October 22. Attendance 300.

Denver

Some Epoch-Making Scientific Advances within the Last One Hundred Years, by B. F. Howard, The Mountain States Telephone and Telegraph Co. November 20. Attendance 33.

Erie

The Metric System, by Howard Richard, Secretary of the Metric Association. A buffet luncheon was served. November 17. Attendance 65.

Fort Wayne

Transformers and Reactors in Radio, by R. H. Chadwick, General Electric Co. Motion pictures on the action of radio receiving tubes were shown. November 12. Attendance 40.

Ithaca

The Power System of Alabama, by F. G. Switzer and J. G. Tarboux. November 20. Attendance 50.

Lehigh Valley

Automatic Stations and Their Remote Supervision, by Chester Lichtenberg, General Electric Co. October 30. Attendance 50.

Power—Electrical and Personal, by Farley Osgood, Consulting engineer and Past-President of the A. I. E. E.;

Developments in Control of Mine Equipment, by H. D. James, Westinghouse Electric & Mfg. Co., and

Business Engineering, by J. H. Pierce, Buck Run Coal Company. The three above addresses were given November 13 and an inspection trip was made to the Lansford Coal Company and the Lehigh Coal and Navigation Company November 14. Attendance 200.

Los Angeles

Automatic Substations and Power Conversion for Railway Purposes, by L. J. Turley, Los Angeles Railway Co., December 1. Attendance 118.

Lynn

Dream Pictures, by Branson DeCou. This was in the form of a musical travelog, illustrated with masterpieces of art and photography. November 23. Attendance 580.

Industrial Heating by Electricity, by N. R. Stansel, General Electric Co. Illustrated with slides. December 2. Attendance 100.

Madison

Natural Electricity and Lightning Protection, J. Slepian, Westinghouse Elec. & Mfg. Co. November 27. Attendance 80.

Mexico

Substations, by L. M. Speirs, Mexican Light & Power Co. November 5. Attendance 34.

Milwaukee

The History of Cooperation Among Engineers, by W. M. White, Allis Chalmers Mfg. Co.

Activities of A. I. E. E. in Great Lakes District, by Professor Edward Bennett, University of Wisconsin. A film, entitled "Milwaukee Electrically" was shown. Dinner meeting. November 23. Attendance 75.

Minnesota

Some Contemporary Advances in Radio Communication, by Professor C. M. Jansky, University of Minnesota. November 30. Attendance 100.

Niagara Frontier

Radio Development, by C. W. Horn, Westinghouse Electric & Mfg. Co. November 6. Attendance 35.

Some Fundamental Properties of the Electron, by Professor V. Karapetoff, Cornell University. December 7. Attendance 123.

Pittsfield

Certain Researches and Hobbies, by Dr. W. R. Whitney, General Electric Co. November 17. Attendance 280.

Round-table discussion on fundamental considerations of power limits of transmission systems with special reference to stability. Mr. R. E. Doherty, General Electric Co., led the discussion by abstracting his paper "Fundamental Considerations of Power Limits of Transmission Systems." December 8. Attendance 60.

Portland

Public-Service Management, by F. T. Griffith, Portland Electric Power Co. A motion picture, entitled "Modern Pioneers" was shown. November 18. Attendance 165.

Providence

The Quest of the Unknown, by Professor H. B. Smith, Worcester Polytechnic Institute. December 2. Attendance 50.

Rochester

Automatic Train Control. This illustrated lecture was written by W. H. Reichard, General Railway Signal Co., but presented by one of his assistants. November 6. Attendance 50.

Saskatchewan

Advances of Physical Science from the Electrical Viewpoint, by Dr. E. L. Harrington, University of Saskatchewan. November 27. Attendance 65.

Schenectady

Smoker. October 23. Attendance 350.

The Quest of the Unknown, by Professor H. B. Smith, Worcester Polytechnic Institute. Illustrated with slides. November 13. Attendance 310.

Springfield

Electric Propulsion of Ships, by W. E. Thau, Westinghouse Elec. & Mfg. Co. Illustrated with slides. November 23. Attendance 56.

Toledo

Police, Fire and Traffic Signal Systems, by Tyler Green, Chief City Electrician. After the lecture an inspection trip to an engine house was made. November 18. Attendance 35.

Toronto

Electric Steam Generators, by C. E. Sisson, Canadian General Electric Co. November 13. Attendance 63.

Watthour Meters, Demand Meters and Kv-a. Meters, by E. G. Ratz, Canadian Westinghouse Co. Illustrated with slides, and

Recent Developments in Relays, by L. N. Crichton, Westinghouse Elec. & Mfg. Co. November 27. Attendance 100.

Utah

Switchboards and Switches, by S. W. Mauger, General Electric Co. Illustrated with slides and moving pictures. October 21. Attendance 44.

Carrier-Current Communication, by R. E. Pierce, Utah Power & Light Co., and

Temperature and Motor Endurance, by Leo Brandenberger, Electrical Engineer. Illustrated with moving picture. December 2. Attendance 46.

Vancouver

Radio, by Dr. H. Vickers, University of British Columbia. Illustrated with slides. December 1. Attendance 61.

Washington

Municipal Electrical Regulation, by A. R. Small, National Fire Protection Association. December 8. Attendance 112.

Worcester

Transmission of Pictures over Wires, by R. D. Parker, American Telephone and Telegraph Co. Illustrated with slides. November 19. Attendance 75.

BRANCH MEETINGS

Alabama Polytechnic Institute

A motion picture, entitled "White Coal," was shown. November 18. Attendance 38.

The Tunnel under the Hudson River, by Mr. Earnest;

The Development of the Steam Locomotive, by Mr. Stain. Mr. Allen gave a talk on his work with the Westinghouse Company. Joint meeting with A. S. M. E. December 2. Attendance 21.

Armour Institute of Technology

Smoker. November 18. Attendance 72.

Wired Wireless, by R. U. Hagen, Illinois Bell Telephone Co. Illustrated. December 3. Attendance 59.

University of Alabama

Talks on membership in the A. I. E. E. were given by F. R. Maxwell, Jr., C. E. Rankin and E. H. Pritchett. Moving pictures, entitled "Back of the Button (Electrical)" and "How Uneeda Biscuits Are Made," were shown. November 16. Attendance 14.

Brooklyn Polytechnic Institute

Radio Meters and Their Application, by Mr. Banks, Jewell Electric Instrument Co., and

Transmission of Motion Pictures by Radio, by Joseph Heller, student. November 24. Attendance 50.

Inspection trip to the new Swedish liner "Gripsholm." December 5. Attendance 50.

University of California

Business Meeting. The following officers were elected: Faculty Advisor, T. C. McFarland; Chairman, E. A. Fenander; Vice-Chairman, E. L. Ramer; Secretary, C. F. Dalziel; Treasurer, G. B. Kenline. November 24. Attendance 25.

University of Cincinnati

Miami Fort Power Plant, by J. R. Hartman, Columbia Gas and Electric Co. Illustrated with slides. November 12. Attendance 75.

Power Transmission, by Professor A. M. Wilson, University of Cincinnati. November 19. Attendance 70.

Clarkson College of Technology

A talk on his experiences while working with the General Electric Company was given by Edward Augustine. November 17. Attendance 21.

Clemson Agricultural College

Past, Present and Future of Industrial Accident Prevention, by J. A. Davis;

The Economics of Safety, by F. A. Burley;

Safety Work at the Plants of the Southern Manganese Corporation, and Federal Phosphorous Company, by F. J. Fishburne, and

Current Events, by J. R. Smith. November 5. Attendance 22.

University of Colorado

Officials of the Public Service Company from Denver and Boulder explained the Doherty Training Course offered by the Public Service Company for college graduates. After the meeting the visitors inspected the electrical engineering laboratories of the University of Colorado. November 18. Attendance 60.

Super Power, by H. M. Webber, student, and

Resuscitation from Electric Shocks, by Dr. Gillespie. Demonstrated. December 2. Attendance 55.

University of Denver

The Wave Propagation of High Frequency, by Stewart Ellis, and

A Year's Progress in Lighting, by Earl Reed. November 12. Attendance 15.

A New Departure in Electrical Education, by C. A. Conner, and

Electric Shovels, by O. C. Hawley. December 4. Attendance 21.

Drexel Institute

Recent Progress on the Delaware River Bridge, by Mr. Chase, A. S. C. E. Joint meeting with A. S. M. E. and A. S. C. E. December 4. Attendance 250.

University of Florida

The Development of Steam Turbines, by Mr. Carey, Western Electric Co., and

Heat Insulation, by Mr. Dean. Illustrated with slides. November 16. Attendance 20.

The Action and Development of the Bell Telephone, by Colonel R. L. Boyd, Southern Bell Telephone and Telegraph System. Illustrated with moving pictures. Joint meeting with Benton Engineering Society. December 7. Attendance 50.

Georgia School of Technology

Telephotography, by D. M. Therral, The Southern Bell Telephone Co. Illustrated with slides and photographs. November 24. Attendace 60.

University of Idaho

Experiences in Shops at Schenectady, by Professor Bailey. November 17. Attendance 15.

University of Iowa

Railless Electrical Vehicles, by F. A. Kulas, and

Manufacturing Insulated Copper Wire, by M. C. Little. November 18. Attendance 45.

The St. Lawrence Water Way, by R. H. Lird;

Rural Electrification, by E. F. Miller, and

Electric Locomotive Drives, by D. A. Shaw. November 25. Attendance 48.

Water, by N. C. Grover, United States Geological Survey. Joint meeting with A. S. M. E. and A. S. C. E. December 4. Attendance 53.

Alternating-Current Railways, by J. C. Risius, and

Wilson Dam, by G. Smith. December 9. Attendance 47.

Kansas State College

Summer Work with the Kansas Gas and Electric Company, by A. L. Brady. November 26. Attendance 76.

University of Kansas

Economics in Engineering, by Professor John Ise. December 3. Attendance 59.

Annual Banquet. December 10. Attendance 173.

University of Kentucky

Business Meeting. The following officers were elected: President, J. W. Weingartner; Secretary, C. E. Albert. October 7.

University of Maine

Business Meeting. The following officers were elected: Chairman, S. B. Coleman; Vice-Chairman, R. A. Parkman; Secretary, H. S. McPhee; Treasurer, R. M. Noyes. November 24. Attendance 9.

Massachusetts Institute of Technology

Uses of Vacuum Tubes, by O. M. Hovgaard, student. November 27. Attendance 21.

Inspection trip to plant of the General Electric Company at Lynn. December 2. Attendance 5.

Michigan State College

Business Meeting. November 17. Attendance 17.

A film, entitled "White Coal," was shown. November 24. Attendance 80.

School of Engineering of Milwaukee

Lightning Arresters, by R. N. Selleg, Westinghouse Electric & Mfg. Co. October 31. Attendance 56.

Business Meeting. The following officers were elected: Chairman, S. A. Moore; Vice-Chairman, Carl Herr; Secretary, B. J. Chromy; Treasurer, W. G. Peck. November 19. Attendance 25.

Missouri School of Mines and Metallurgy

Loud Speakers, by Dryden Hodges. December 4. Attendance 14.

University of Missouri

Talks were given by students on their Summer experiences working for various companies. October 19. Attendance 17.

Bell Telephone Laboratory of New York City, by Professor Grandy. A film on the manufacture of storage batteries was shown. November 2. Attendance 34.

Electrification of Railways—History and Development of Rapid Transit, by Professor Johnson. November 16. Attendance 21.

Montana State College

A moving picture, entitled "The King of the Rails." was shown. November 16. Attendance 162.

The Transmutation of Mercury into Gold. This lecture was read by B. A. Shaw, and

Hydrogen as a Cooling Medium for Electrical Machinery. Read by John Chamberlain. December 7. Attendance 159.

University of Nevada

Transformers, by W. C. Smith, General Electric Co. Illustrated with slides and a model transformer. November 18. Attendance 48.

College of the City of New York

Railway Signals, by James Wilson, student. November 19. Attendance 17.

Inspection trip to the Electrical Testing Laboratories. November 30. Attendance 14.

A report on the test of a 150-kw. alternator was given by Daniel Schneeweis and James Wilson. December 10. Attendance 13.

North Carolina State College

The Life and Work of the Late J. B Duke, and

Report of Committee on Production and Application of Light, by E. W. Chadwick. November 3. Attendance 36.

Methods of Resuscitation, by Captain Gordon, Red Cross Life Saving Corps. November 17. Attendance 45.

University of North Carolina

Hydrogen-Cooled Generators, by W. E. Wortman, student. November 19. Attendance 20.

University of North Dakota

Sightseeing in a Large Manufacturing Plant, by Professor D. R. Jenkins;

A New Theory of Light, by Elmer Johnston, student, and

Permalloy, by Helmer Gronhovd, student. November 16. Attendance 30.

The Vacuum Tube, by Karl Rudser, student, and

Muscle Shoals, by Merton Peterson, student. November 30. Attendance 15.

Northeastern University

Business Meeting. The following officers were elected: Chairman, F. W. Morley; Vice-Chairman, E. O. Alden; Assistant Secretary-Treasurer, L. C. Tyack. November 27. Attendance 21.

University of Notre Dame

Short-Wave Propagation, by Frank Castro, and

Heating as Your Job, by Mr. Strawbridge, Indiana and Michigan Elec. Co. November 2. Attendance 31.

A Comparison of Electrically Driven Centrifugal Oil Pumps with Steam-Driven Reciprocating Pumps, by M. B. Daly, and

The Milky Way, by Rev. Emil de Wulf. Illustrated. November 16. Attendance 26.

Ohio Northern University

Business Meeting. December 10. Attendance 15.

Ohio State University

Arc Welding, by E. K. Lincoln, Lincoln Electric Co. November 20. Attendance 180.

Oklahoma Agricultural and Mechanical College

Rural Electrification, by Earl Miller, student. Illustrated. November 18. Attendance 19.

University of Oklahoma

A Brake Test on a 0.000,001-H. p. Motor, by Prof. O. W. Walter;

Local Engineering, by Bruce Spence;

Electric Meters, by Floyd Williams, and

High-Line Maintenance, by Ralph Tyler. November 19. Attendance 32.

Pennsylvania State College

Business Meeting. October 28. Attendance 40.

A film, entitled "The Queen of the Waves," was shown. Professor L. A. Doggett gave a talk in which he described the electrical installations of the U. S. S. New Mexico, the U. S. S

Saratoga and other battleships. He also gave an explanation of the action of the gyro-compass and its installations. November 18. Attendance 100.

Canal Zone, by G. J. Cartwright;

Bell Telephone Laboratories, by D. A. McMaster;

New York Edison Company, by J. E. Hogan, and

Westinghouse Elec. & Mfg. Company, by Professor H. I. Tarpley. These talks dealt with recent Summer experiences of some of the members. December 9. Attendance 52.

University of Pittsburgh

Pittsburgh Railways Problems, by G. A. Culbertson, student;

Purification of Circuit-Breaker Oils, by R. L. Johnson; student and

Recent Developments in Palestine, by A. Abulafia, student. November 6. Attendance 29.

Machine-Switching Telephones, by S. H. King, student. November 13. Attendance 26.

The Klydonograph, by E. H. Powell; student;

The Manufacture of Steel Pipe, by D. P. Mitchell, student, and

Harnessing the Tides of the Bay of Fundy, by N. Watkins, student. November 20. Attendance 25.

Purdue University

The Use of Electrical Analogies in Solving Mechanical Problems, by J. A. Long, American Tel. & Tel. Co., and

Telephone Apparatus in the Purdue Telephone Laboratory, by E. B. King, Indiana Bell Telephone Co. October 26. Attendance 40.

Improving Consumer Substations, by A. W. Miller, student, and

Transformer Design and Operation, by A. M. Wiggins, student. November 10. Attendance 80.

The Electric Railway and Its Relation to Industry, by Professor D. D. Ewing, and

Swordfishing, by Professor J. L. Bray. December 1. Attendance 100.

Rensselaer Polytechnic Institute

Work with the New York Edison Company, by Fred Van Olinda;

Work with the United Electric Light and Power Company, by Louis M. Dowell;

Work with Kingston Public Utilities Company, by Luke Holton;

Work with the New Haven Power and Light Company, by Paul Escholtz;

Work with the General Electric Company, at Springfield, by Leslie Hochgraf;

New Methods of Making Transmission-Line Surveys, by Dr. Wm. L. Robb;

New Alloy for Spark-Plug Points, by Dr. M. A. Hunter;

Physics and the Theory of Relativity, by Dr. R. A. Patterson and

Making an Interference Survey by Radio, by Dr. W. J. Williams. November 10. Attendance 106.

Rhode Island State College

The Life and Work of Oliver Heaviside, and

The Einstein Theory of Relativity, by Professor Anderson. November 20. Attendance 27.

The Melrose Substation, by J. Lamb. December 4. Attendance 18.

Rose Polytechnic Institute

Principles of Street Lighting, by G. F. Mudgett, Westinghouse Elec. & Mfg. Co. November 11. Attendance 41.

High-Frequency Waves, by D. R. Werner. December 2. Attendance 43.

South Dakota State School of Mines

Telephone Engineering, by Fred Spain. November 16. Attendance 16.

Swarthmore College

Engineering as a Profession, by A. Prescott Willis. December 10. Attendance 50.

Syracuse University

Business Meeting. The following officers were elected: President, K. N. Cook; Secretary, R. H. Watkins; Treasurer, G. R. Brownell. September 23. Attendance 20.

Commercial Research Engineering, by W. E. Mueller. September 30. Attendance 19.

High-Tension Cables, by E. L. Dunlap. October 7. Attendance 18.

Automobile Braking Systems, by G. R. Brownell. October 14. Attendance 17.

The Dufour High-Frequency Oscillograph, by L. F. Busse. October 21. Attendance 19.

Piezo Crystals and Piezo Electricity, by B. C. Carpenter. October 28. Attendance 19.

The Klydonograph and Its Application to Surge Investigation, by K. N. Cook. November 4. Attendance 20.

Carrier Telephony on High-Voltage Lines, by C. N. Coombe. November 11. Attendance 20.

Street-Railway Power and Line Distribution, by E. R. Fitzgerald. November 18. Attendance 20.

Texas Agricultural and Mechanical College

High-Voltage Transmission Lines, by D. M. Davis, student, and

Power-Plant Design, by R. M. Kennedy, student. November 20. Attendance 83.

Virginia Military Institute

A New Departure in Engineering Education, by Cadet S. A. Carson;

Losses in Iron under the Action of Superposed A-C. and D-C. Excitations, by Cadet L. Metcalfe, and

Electricity as Applied to Medicine, by Cadet R. L. Yeager. December 7. Attendance 21.

Virginia Polytechnic Institute

The New Orthophonic Victrola, by A. R. Green;

New Courses Offered by the University of Pennsylvania, by Mr. Keller, and

The Corn Products Refining Plant, by H. E. Broyles. November 18. Attendance 25.

The Wireless, by Professor Haynes. December 2. Attendance 35.

University of Virginia

A film, entitled "Speeding Up Our Deep-Sea Cables," was shown. November 16. Attendance 23.

University of Washington

The Development of the Submarine Cable, by M. T. Crawford, Puget Sound Power and Light Co. Illustrated with slides. November 4. Attendance 27.

West Virginia University

What Mental Tests Will Do in Industries, by W. L. Nuhfer;

Dipping and Baking Railway-Motor Armatures, by W. F. Davis;

Babbitt Metal, by G. R. Latham;

Advantages of Highway Lighting, by W. A. Williams;

Steam Geysers and Electrical Development, by E. A. Berry;

A Thermostat, by S. McGowan, and

Highway Lighting, by C. W. Moore. November 23. Attendance 28.

Business Meeting. November 30. Attendance 28.

University of Wisconsin

The Value of Non-Professional Subjects to the Engineer, by Professor Edward Bennett;

Accuracy in Engineering Work, by Professor C. M. Jansky, and

The Value of Membership in the Student Branch and National A. I. E. E., by Professor J. T. Rood. November 10. Attendance 140.

Worcester Polytechnic Institute

Business Meeting. The following officers were elected: Chairman, O. H. Brewster; Vice-Chairman, D. A. Calder; Secretary, R. A. Beth; Treasurer, J. F. Wood: Counselor, H. A. Maxfield. November 19. Attendance 21.

My Travels in Mohammedan Countries, by Professor H. B. Smith. December 8. Attendance 60.

University of Wyoming

Business Meeting. The following officers were elected: Chairman, Everett Murray; Vice-Chairman, James Yates; Secretary-Treasurer, Virgil Shinbur; Faculty Advisor, G. H. Sechrist. November 19. Attendance 9.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ELECTRICAL DESIGNER, who has had experience on oil switches. Salary $200-$250 a month. Location, Chicago. R-7818-R-7-C.

DESIGNER, for manufacturing purposes of such equipment as air break switches, gang operated disconnect switches, bus supports, etc. Experience in simple station operation, design of substations, etc., does not qualify a man for this position. Experience in the actual design and manufacture of the class of equipment described essential. Location, Pennsylvania. R-8118-C.

SALES ENGINEER, technical graduate, for manufacturer of storage batteries. Opportunity. Apply by letter stating age, education and experience. Location, Georgia. R-8208-C.

ELECTRICAL ENGINEER, experienced in developing small electrical machines and devices. Knowledge of spot welding and heat resistance units desirable. Apply by letter stating experience, age, education and salary desired. Location, Middlewest. R-8243-C.

SALES ENGINEER, for manufacturer of electrical heating and control appliances. Apply by letter. Location, San Francisco. R-8257-C-S.

DESIGNING ENGINEER, 30-35, with electrical crane and hoist experience. Apply by letter. Salary $3000 a year. Location, Pennsylvania. R-8205-C.

MEN AVAILABLE

EXECUTIVE, 43, married, thoroughly competent to take charge of offices, plant or factory. Many years' actual experience in organization, personnel management, valuation and appraisal, installations and supervision, office management, correspondent and special confidential investigations. Available at once. Location, New York or New Jersey. C-521.

ENGINEERING EXECUTIVE, position desired with growing company in commercial or engineering capacity, preferably as department head, or assistant to general executive. At present assistant to chief engineer company manufacturing heavy machinery. Ten years' experience since graduation from Rensselaer Polytechnic Institute in design, manufacture heavy machinery, design, manufacture electrical equipment, appraisal of physical property of public service corporations, maintenance of shop equipment, and power plant operation. Authority on application of industrial electrical equipment. Available because of closing of plant with which connected for past seven years. A-280.

PLANT ENGINEER, age 33, technical education, broad experience in the design, construction and maintenance of industrial plants. Specialty oil refineries. New York license. Available immediately. B-9376.

ENGINEER-SCIENTIST, 30, married, educated at M. I. T., three years in chemistry, three years in mathematical physics, graduating in mechanical engineering. Employed as technical report writer for research laboratory of G. E. and as industrial physicist and designer by Corning Glass Works. Executive experience and broad training in commercial subjects. Employed. B-9930.

ENGINEERING EXECUTIVE, nine years' experience, mainly with one large power company in station operation, distribution lines, substation construction, transmission line construction, distribution engineering, commercial work including power sales. Now district superintendent charge distribution entire district, also entire charge local offices reporting to district office. Graduate electrical engineer, G. E. test course training. Wants place as assistant to chief engineer, or general manager electric power company, or in consulting engineering firm. Married, 32. C-650.

ENGINEERING EXECUTIVE, 44, married, considerable experience selection, installation, operation wide variety electrical and mechanical equipment. G. E. test, sales engineering, steel mill superintendent. Successful record building efficient operating organization. Effective in practical analysis and presentation of industrial problems. Refer present employer. Available January first. Location anywhere. C-615.

ELECTRICAL ENGINEER, 30, technical graduate, desires position as assistant engineer or executive. Eighteen months G. E. test, four years assistant foreman on installation, testing and development work. Will not consider a place that has no chance for advancement. Location, greater New York City. Available on two weeks' notice to present employer. C-702.

ELECTRICAL ENGINEER, college graduate with five years' experience in power house and substation design, as well as construction, desires responsible position with public utility or engineering firm, offering opportunity. Available on reasonable notice. C-692.

ELECTRICAL ENGINEER, research, designing and executive practice, particularly in gasoline-electric traction problems, fully acquainted with theory and practice of electrical, electro-physical and mechanical problems and shop practice, desires responsible permanent position. At present chief and consulting engineer. Available in short time. Pittsburgh or East preferred. C-693.

GRADUATE OF THE UNIVERISTY OF PENNSYLVANIA in industrial management, four years' experience in electrical construction, drafting and machine design in executive capacity. Age 26. Available January 15, 1926. C-694.

ELECTRO-PHYSICIST AND RADIO ENGINEER, age 40, married, former professor in Russian technical colleges; publications and inventions in x-rays, positive rays, radio, measuring instruments, agricultural applications. Two years' industrial experience in radio receivers and parts in United States. Employed in testing laboratory of radio concern. Desires research, radio engineering, or testing position. Available on one week's notice. B-371.

ELECTRICAL AND VALUATION ENGINEER, 32, single, good working knowledge Spanish. Ten years' practical experience installation, operation of steam, hydro-electric plants, electric mining, industrial and public utility equipment, including two years General Electric Company's tests, two years with Public Service Commission of New York State. Now specializing in inventories, appraisals, property reports, investigations, classified accounting systems for public utilities, mining and industrial corporations. Salary $300 per month. B-9636.

ELECTRICAL AND MECHANICAL ENGINEER, 45, married, with very wide experience in dredging, construction and executive work, desires a permanent position with public utility, or consulting, or construction firm. Willing to go anywhere. Perfect knowledge of modern languages. Available end of January or earlier. C-720.

ELECTRICAL ENGINEER, 25, single, Columbia graduate 1925, extensive training of six years with ability to use his hands and his head; ten years' electrical and mechanical shop experience, seven months' experience in test department of large power company, desires a position with a manufacturing company where there is an opportunity for advancement. Wishes to specialize in electric relays and control devices and would be most interested in this work. Available on two weeks' notice. Location, anywhere. C-237.

TECHNICAL GRADUATE, desires position with established radio manufacturing concern, domestic or foreign. Present position with U. S. Government on care, upkeep, and maintenance of radio direction finding stations. C-723.

PROFESSOR, electrical engineering, would consider making a change. Ten years' of teaching experience. Well acquainted with industrial requirements through design, application and construction experience. Desires professorship in an institution where research is encouraged. B-7083.

STUDENT ENGINEER, age 22, single, seventeen months on G. E. test, desires position in power plant, preferably in connection with generation and transmission. Available on two weeks' notice. Location, New England, or Eastern New York. C-731.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED DECEMBER 11, 1925

AGENS, HERBERT M., Asst. to Electrical Engineer, The Foundation Co., 120 Liberty St., New York, N. Y.

ARMERO, JOSE P., Electrical Engineer, Operating Dept., Alabama Power Co., Birmingham, Ala.

BARBER, HARRY ORVAL, Supt., Snoqualmie Falls Generating Sta., Puget Sound Power & Light Co., Snoqualmie, Wash.

BATES, L. W., Engineer in charge of Automatic Substations, Appalachian Power Co., Bluefield, W. Va.

BOOTHE, EUGENE F., Electrician, Marshall Electric Co., 3225A Locust St., St. Louis, Mo.

BUSCH, HUGO WILLIAM, Designing & Maintaining of Test Equipment, Ware Radio Corp., 543 West 42nd St., New York, N. Y.

CARVER, DELMONT WILSON, Charge of Meter Dept., Brevard County Power Co., Melbourne, Fla.

CASSELL, WALLACE LEWIS, Instructor, Elec. Engg. Dept., University of Colorado, Boulder, Colo.

CAYLOR, RALPH A., Service Manager, The E. H. Walker Co., 210-212 N. Erie St., Toledo, Ohio.

CHRISTIE, SOREN L., Jr., Electrical Engineer, Elec. Heating Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

CLANCEY, JOSEPH A., Jr., Production Manager, Gray Electro Chemical Laboratory, Inc., 9-11 W. 20th St., Bayonne, N. J.

*CONNOLLY, ROBERT COTTMAN, Asst. Electrical Engineer, Western Sugar Refinery, San Francisco, Calif.

CONOLEY, ALEXANDER GORMAN, Division Line Inspector, American Tel. & Tel. Co., 928 Hurt Bldg., Atlanta, Ga.

*CORCORAN, HARRY ROBERT, Sales Engineer, Electric Controller & Mfg. Co., 2700 E. 79th St., Cleveland, Ohio.

*CRANKALL, RICHARD JOHN, Technical, Writer, Engg. Dept., National Lamp Works, General Electric Co., Nela Park, Cleveland, Ohio.

CULLINAN, CORNELIUS, Construction Superintendent, Public Service Production Corp., 15 E. Park St., Newark, N. J.

DANCE, HERBERT ERNEST, Asst. Consulting Engineer, Lecturer, Elec. Engg. Dept., Birkenhead Technical School, Birkenhead, Eng.

DAVIS, ROWLAND FENNER, Engineer, O. & E. Dept., American Tel. & Tel. Co., 195 Broadway, New York; res., Brooklyn, N. Y.

DEAN, SAMUEL MILLS, Engineer, The Detroit Edison Co., 2000 Second Ave., Detroit, Mich.

DEARLOVE, TOM CARLTON, Electrical Engineering, 19 Homewood Ave., Toronto, Ontario, Can.

*de VEYHER, CONSTANTIN, Fieldman, Transmission Engg. Dept., So. California Telephone Co., 433 S. Olive St., Los Angeles, Calif.

DIGGINS, GEORGE J., Jr., Asst. Engineer, Railway Electrification, Gibbs & Hill, Pennsylvania Sta., New York, N. Y.

DRUSHEL, RAYMOND WENDELL, Division Operator, The Ohio Public Service Co., Alliance, Ohio.

ECKERSLEY, JAMES, Foreman, Meter Dept., Toronto Hydro-Electric System, 225 Yonge St., Toronto, Ont., Can.

ELBERTY, ROBERT S., Jr., Engineer, American Laundry Machinery Co., Norwood; res., Cincinnati, Ohio.

*FANAFF, PAUL ANDREW, Electrical Work, 628 Ogden Ave., Toledo, Ohio.

FLEMING, WILLIAM RAYMOND, Electrical Switchboard Operator, Commonwealth Edison Co., Fisk Street Station, Chicago, Ill.

GARDNER, JOHN H., Jr., Captain, U. S. A., Fort Hayes, Columbus, Ohio.

GETTESS, GEORGE HAROLD, Engineer, The Detroit Edison Co., 2000 Second Ave., Detroit, Mich.

GLAZIER, FORREST SMOOT, Sales Engineer, W. A. Ramsay, Ltd., 74 S. Queen St., Honolulu, T. H.

GRISWOLD, RALPH G., Instructor, Elec. Engg. Dept., Purdue University, West Lafayette, Ind.

HARDY, ROBERT S., Asst. General Manager, Niagara Lockport & Ontario Power Co., 608 Lafayette Bldg., Buffalo, N. Y.

*HOFFMAN, HENRY JULIUS, Student Engineer, General Electric Co., Erie, Pa.

HORN, HENRY GEORGE, Designing Engineer, General Electric Co., Pittsfield, Mass.

*HOWERTH, DWIGHT GOLDWIN, Asst. to Statistician, Adirondack Power & Light Corp., Clinton St., Schenectady, N. Y.

HUBBARD, McCOY, Asst. Engineer, Southern Utilities Co., West Palm Beach, Fla.

HUBINGER, JOSEPH EDWARD, Jr., Construction Dept., Mississippi River Power Co., Keokuk, Iowa; for mail Warsaw, Ill.

ISAAC, ARCHIBALD CHARLES THOMPSON, Mechanical Engineer, General Electric Co., Pittsfield, Mass.

JOHNSTON, ROBERT FOSTER, Estimator, General Electric Co., 120 Broadway, New York, N. Y.

KOLDOFF, ANTHONY GEORGE, Cabling Engineer, Western Electric Co., Inc., 24th St., & Cicero Ave., Cicero; res., Elmhurst, Ill.

KOPATZKE, GEORGE A., Service Manager, Wagner Electric Corp., 501 Broadway, Milwaukee, Wis.

*KWONG, FREDERICK KIMMING, Chief Engineer, Toi-shan Electric Light & Power Co., Ltd., 97 Wing Lok St., Hongkong, China.

LARSON, NILS GERON, Electrical Drafting, The International Paper Co., 100 E. 42nd St., New York, N. Y.

LEROY, EVERETT ROOSEVELT, Engineering Assistant, New York Telephone Co., 104 Broad St., New York, N. Y.

LOCHNER, BJORN R., Draftsman, Westinghouse Elec. & Mfg. Co., Sharon, Pa.

LOSINSKY, JACOB, Control Engineer, Volhov Hydro-Electric Power Plant Works, A. S. E. A., Ludvika, Sweden.

MARSH, HALLOCK SNYDER, Service Clerk, Radio Corp. of America, 925 Fort St., Honolulu, T. H.

MILTON, ROBERT McCARLEY, Electrical Inspector, U. S. Engineer's Office, Wilson Dam, Florence, Ala.

*McNAIR, J. W., Engr. Assistant, United Electric Light & Power Co., 56 Cooper Square, New York, N. Y.

McNALLY, CLAUDE, Electrical Instructor & Engineer, Academy High School, Erie, Pa.

MILLER, WILLIAM G., Electrical Engineer, Designing Dept., Electric Bond & Share Co., 71 Broadway, New York, N. Y.

NUTTALL, BRANSON, Switchboard Engineer, Messrs. Ferguson Pailin Ltd., Higher Openshaw, Manchester, Eng.

PARRY, EDWARD M., 202 Howard St., Passaic Park, N. J.

PALMER, HARLAN B., Instructor, Elec. Engg. Dept., University of Colorado, 810 14th St., Boulder, Colo.

PETTERSEN, HERBERT CHRISTIAN, Draftsman, Inside Plant Dept., Commonwealth Edison Co., 72 W. Adams St., Chicago,, Ill.

PULLEN, JOHN THOMAS, Jr., Asst. Engineer, Southern Utilities Co., West Palm Beach, Fla.

PYLE, MARK, Engineer, Puget Sound Power & Light Co., Eastern Dist., Wenatchee, Wash.

QUINN, JOSEPH JOHN, Estimating Engineer, Engg. Dept., Duquesne Light Co., 435 6th Ave., Pittsburgh, Pa.

*RICHARDS, KENNETH WEATHERBY, Cadet Engineer, Public Service Electric & Gas Co., Newark, N. J.

ROBINSON, TREVOR ARMSTRONG, Draughtsman, Northern States Power Co., 76 W. 3rd St., St. Paul, Minn.

ROITBURD, BERNARD, 2905 Grand Concourse, Bronx, New York, N. Y.

ROTE, OAKLEIGH C., Student Engineer, General Electric Co., Schenectady, N. Y.

RUDERSHAUSEN, FRANZ JOSEF, Laboratory Assistant, Chile Exploration Co., Chuquicamata, Chile, So. Amer.

RUMP, SIGURD, Yarmouthville, Maine.

SALERNO, MARCUS JOSEPH, 515 W. 111th St., New York, N. Y.

SANDSTROM, PER N., Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

SAYRE, EARL ROLAND, Sales Engineer, Hart & Hegeman Co., 623 W. Jackson Blvd., Chicago, Ill.

SCHENCK, IRVING PRIESTLEY, Electrical Engineer, Day & Zimmerman, 1600 Walnut St., Philadelphia, Pa.; for mail, Plainfield, N. J.

SCLAVOUNOS, LAMPROS P., Manager, Member, Board of Directors, The Egyptian Radio Co., Cheriff Pacha Street 16, Alexandria, Egypt.

SCOTT, ARTHUR H., Engineer, General Electric Co., Pittsfield, Mass.

SIMPSON, WALTER LA VERN, Electrical Engineer, Canadian & General Finance Co., 357 Bay St., Toronto, Ont., Can.

SIVIAN, LEON J., Research Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

SOCOLOFSKY, PAUL, Student, Industrial Elec. Engg. Dept., Pratt Institute, 254 Clermont Ave., Brooklyn, N. Y.

STAROSSELSKY, DMITRY V., Inspector, Electrical Construction Bureau, Brooklyn Edison Co., Pearl & Willoughby Sts., Brooklyn, N. Y.

STEWART, PHILIP BRUCE, Supt. of Transmission, Union Gas & Electric Co., 4th & Plum Sts., Cincinnati, Ohio.

SUMMERS, CHARNELLE H., Jr., Asst. Distribution Engineer, Southern Utilities Co., West Palm Beach, Fla.

TAYLOR, PAUL B., Instructor, Engineering School, Drexel Institute, Philadelphia, Pa.

THOMAS, WINTHROP ATHERTON, Asst. Engineer, Elec. Engg. Dept., New York Edison Co., 124 E. 15th St., New York, N. Y.

*THOMASON, FREDERICK LAYTON, Engineer, Murrie & Co., 45 E. 17th St., New York; res., Brooklyn, N. Y.

THOMPSON, SUMNER MATELL, Electrical Inspector, Bureau of Power & Light, City of Los Angeles, 120 E. 4th St., Los Angeles, Calif.

WILKINSON, GEORGE DAVID, Division Traffic Inspector, Western Union Telegraph Co., 24 Walker St., New York, N. Y.

*WOOD, A. ROYAL, Ass't Supervisor, The Philadelphia Electric Co., 2301 Market St., Philadelphia, Pa.

Total 82

*Formerly Enrolled Students

ASSOCIATES REELECTED DECEMBER 11, 1925

ASHLEY, ALLEN, Special Representative, Condit Electrical Mfg. Corp., 152 W. 42nd St., New York, N. Y.

TUCKER, ALLAN WINTHROP, Member, Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.; res., West New York, N. J.

MEMBERS ELECTED DECEMBER 11, 1925

BOLIS, PIETRO, Chief Engineer, Transformer Factory, Compagnia Generale di Elettricita, Via Borgognone, 40, Milan, Italy.

DOW, JAY L., Telephone Engineer, Bell Tel. Laboratories, Inc., 463 West St., New York, N. Y.

DREESE, ERWIN ERNEST, Chief Engineer, Lincoln Electric Co., Cleveland, Ohio.

PERSHAD, BALA, Supt., Telephone Dept., H. E. H., The Nizam's Government, Hyderabad, Deccan, India.

RUTH, CONANT W., President, C. W. Ruth Engineering Co., 8 S. Dearborn St., Chicago, Ill.

SCUDDER, FREDERICK J., Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

VAN MEETEREN, WILLIAM, General Manager, Siemens-Mexico, S. A., Puente de Alvarado, 91-99, Mexico, D. F., Mex.

TRANSFERRED TO GRADE OF FELLOW DECEMBER 11, 1925

PANNELL, ERNEST V., Technical Advisor to the British Aluminum Co., New York, N. Y.

TRANSFERRED TO GRADE OF MEMBER DECEMBER 11, 1925

BAILEY, EDGAR L., Electrical Engi eer, Detroit, Mich.

BARTON, ROBERT C., Engineer on Construction Methods, Pacific Tel. & Tel. Co., San Francisco, Calif.

BROWN, HARRY F., Assistant Electrical Engineer, N. Y., N. H. & H. R. R. Co., New Haven, Conn.

CAMP, C. R., Head Draftsman, Commonwealth Edison Co., Chicago, Ill.

CANNADY, N. E., State Electrical Engineer, Raleigh, N. C.

CODDING, HENRY W., Assistant Engineer, Elec. Engg. Dept., Public Service Production Co., Newark, N. J.

COLEY, WALTER R., Plant Superintendent, Leeds & Northrup Co., Philadelphia, Pa.

CROTHERS, HAROLD M., Professor of Electrical Engineering, South Dakota State College, Brookings, S. D.

D'ALTON, F. K., Assistant Laboratory Engineer, Hydro-Electric Power Commission of Ontario, Toronto, Ont.

DANA, ALAN S., Research Engineer, Kerite Insulated Wire & Cable Co., Seymour, Conn.

DAVIS, LEE I., Test Engineer, Otis Elevator Co., Yonkers, N. Y.

DuBOIS, DELAFIELD, Electrical Research Engineer, Safety Insulated Wire & Cable Co., Bayonne, N. J.

FINCH, FLOYD R., Electrical Engineer, General Electric Co., Pittsfield, Mass.

GAGE, DAVID H., Foreign Wire Relations Engineer, Postal Telegraph-Cable Co., 253 Broadway, New York, N. Y.

GEORGE, F. R., Engineer of Operation, Pacific Gas & Electric Co., San Francisco, Calif.

HALL, HERBERT S., Electrical Engineer on Valuation, Murrie & Co., New York, N. Y.

HYER, RAYMOND G., Superintendent Design & Construction, Westchester Lighting Co., Yonkers, N. Y.

JOLLYMAN, JOSIAH P., Chief, Div. of Hydroelectric & Transmission Engineering, Pacific Gas & Electric Co., San Francisco, Calif.

KRUG, FREDERICK, Superintendent of Power Production, Porto Rico Railway, Light & Power Co., San Juan, P. R.

MACK, CARL T., Attorney at Law, Patent Causes, Washington, D. C.

MAC LAREN, MALCOLM, Professor of Electrical Engineering, Princeton University, Princeton, N. J.

McCABE, GORDON B., Technical Engineer Operating Dept., Detroit Edison Co., Detroit, Mich.

METZENHEIM, HENRY H., Instructor in Electricity & Mathematics, Newark Technical School, Newark, N. J.

MICHETTI, O. D., Lieut. Commander, Engineering, Argentine Navy, Quincy, Mass.

PAXTON, E. B., Engineer, General Engineering Dept., General Electric Co., Schenectady, N. Y.

REID, MEREDITH W., Electrical Engineer, General Engineering & Management Corp. New York, N. Y.

RUSSELL, ROY E., Estimator, Frank J. York, Co., Detroit, Mich.

SMITH, LOUIS G., Assistant to General Superintendent, Consolidated Gas, Electric Light & Power Co., Baltimore, Md.

SNYDER, EDWARD B., Manager, Sales & Engineering, Hi-Tension Ins. Div., Ohio Brass Co., Mansfield, Ohio.

SPOONER, HENRY W., Engineer, The Foundation Co., New York, N. Y.

STEMLER, EDWARD J., Chief Operator, Interborough Rapid Transit Co., New York, N. Y.

TALBOT, EMMETT D., Engineer, Bell Telephone Laboratories, New York, N. Y.

TOUR, GREGORY I., Assistant Engineer, Stone & Webster, Inc., Boston, Mass.

TRUEBLOOD, HOWARD M., Engineer, Dept of Development & Research, American Telephone & Telegraph Co., New York, N. Y.

VAN NIEUKERKEN, J. M., Assistant Engineer, Cleveland Union Terminals Co., Cleveland, Ohio.

VINET, EUGENE, Assistant to Vice-President in charge of Engineering, Middle West Utilities Co., Chicago, Ill.

WOOD, E. M., Assistant Engineer, Hydro-Electric Power Commission, Toronto, Ont.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held December 7, 1925, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

To Grade of Fellow

BETTIS, ALEXANDER E., Vice-President, Kansas City Power & Light Co., Kansas City, Mo.

CURTIS, HARVEY L., Senior Physicist, Bureau of Standards, Department of Commerce, Washington, D. C.

DANN, WALTER M., Electrical Engineer, Westinghouse Electric & Mfg. Co., Sharon, Pa.

HOBART, K. E., Superintendent Overhead Lines, Commonwealth Edison Co., Chicago, Ill.

PRINCE, DAVID C., Research Engineer, General Electric Co., Schenectady, N. Y.

TO Grade of Member

CAMPBELL, THADDEUS C., Telephone Engineer, Systems Development Dept., Bell Telephone Laboratories, New York.

EWENS, W. SYDNEY, District Manager, Alfred Collyer & Co., Toronto, Ont.

HAZELTINE, HAROLD L., Engineer of Insulation, Sterling Varnish Co., Pittsburgh, Pa.

JOHNSON, EDWARD J., Member of Technical Staff, Bell Telephone Laboratories, New York

MEYER, A. A., Assistant General Superintendent Detroit Edison Co., Detroit, Mich.

NOSS, MARSENA A., Chief Engineer, International Telepost Co., New York.

ROBINSON, BLIGHT S., Engineer, R. W. Cramer & Co., Inc., New York.

SHEPARD, ROBERT B., Electrical Engineer, Underwriters' Laboratories, New York

SILSBEE, FRANCIS B., Physicist, Bureau of Standards, Department of Commerce, Washington, D. C.

SMITH, EVERETT H., Supervising Equipment Design Engineer, Bell Telephone Laboratories, New York.

SNIDER, GEORGE E., Chief Electrical Engineer, Ohio Public Service Co., Cleveland, O.

STEVENS, ALEXANDER C., Electrical Engineer, General Electric Co., Schenectady, N. Y.

WEIGHT, JOHN W., Head, Industrial Truck and Locomotive Dept., Electric Storage Battery Co., New York.

WILKINS, ROY, Assistant Engineer, Dept. of Hydro-Elec. & Transmission Engg., Pacific Gas & Electric Co., San Francisco, Calif.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before January 31, 1926.

Abe, T., Japanese Government Railways, New York, N. Y.

Adam, A. O., Jr., Bell Telephone Laboratories, Inc., New York, N. Y.

Adkins, A. H., Electric Storage Battery Co., Washington, D. C.

Ahrens, J. H., Henry & Wright Mfg. Co., Hartford, Conn.

Ahrling, G. A., Murrie & Co., Inc., New York, N. Y.

Aikins, N. B., New England Tel. & Tel. Co., Portland, Me.

Alexander, G. H. W., Bell Telephone Laboratories, Inc., New York, N. Y.

Alexander, R., Jr., Murrie & Co., New York, N. Y.

Allen, J. P., New York Telephone Co., New York, N. Y.

Allen, L. M., (Member), Bell Telephone Laboratories, Inc., New York, N. Y.

Allison, D. C., General Electric S. A., Mexico D. F., Mex.

Andem, K. S., Public Service Production Co., Newark, N. J.

Anderson, A. S., New Orleans Public Service, Inc., New Orleans, La.

Anderson, E. W. N., Virginia Northern Power Co., Warrenton, Va.

Arnold, O. B., General Electric Co., Schenectady, N. Y.

Auer, G., Automatic Electric, Inc., Chicago, Ill.

Baer, H. J., Metropolitan Edison Co., Reading, Pa.

Baily, F. A. A., Canadian Marconi Co., Montreal, P. Q., Can.

Barber, H. W., Jr., General Electric Co., Lynn, Mass.

Barley, T. T., Public Service Electric & Gas Co., Orange, N. J.

Barringer, F. D., Pratt Institute, Brooklyn, N. Y.

Bartheld, L. P., Bell Telephone Laboratories, Inc., New York, N. Y.

Bartholomew, H. G., New York Telephone Co., New York, N. Y.

Batt, L. T., Public Service Electric & Gas Co., Newark, N. J.

Baumgarten, A. J., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Baxandall, F. M., Commonwealth Power Corp. of Michigan, Jackson, Mich.
Baxter, L. H., Hydro-Elec. Pr. Commission of Ontario, Toronto, Ont., Can.
Bayers, C., Brooklyn Edison Co., Inc., Brooklyn, N. Y.
Bedi, H. S., Public Service Co. of No. Illinois, Chicago, Ill.
Beller, C. J., Cleveland Elec. Illuminating Co., Cleveland, Ohio
Bergen, P. V., Bronx Gas & Electric Co., Bronx, New York, N. Y.
Best, A. O., Ignition & Repair Service Station, Owensmouth, Calif.
Bitterli, J. A., Commonwealth Edison Co., Chicago, Ill.
Bixby, O. M., New York Central Railroad, New York, N. Y.
Blocklin, H. G., Bell Telephone Laboratories, Inc., New York, N. Y.
Blumstein, G., Pullman Car Co., Long Island City, N. Y.
Bobb, L. C., Pennsylvania Power & Light Co., Sunbury, Pa.
Bolstad, A. L., Western Electric Co., Seattle, Wash.
Borge, W. P., Illinois Power & Light Co., Chicago, Ill.
Brandt, C. H., Chas. B. Hawley & Co., Washington, D. C.
Brazier, W., The Canadian Crocker-Wheeler Co., Ltd., St. Catherines, Ont., Can.
Brown, H. H. ,Iowa Electric Co., Cedar Rapids, Ia.
Brown, L. P., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Brown, N. H., Consolidated Steam Specialty Co., Milwaukee, Wis.
Bruce, E., Bell Telephone Laboratories, Inc., New York, N. Y.
Bruhn, H. D., Bell Telephone Laboratories, Inc., New York, N. Y.
Buckner, L. O., American Trona Corp., New York, N. Y.
Bugge, A. F. C., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Bump, R. L., General Electric Co., Bridgeport, Conn.
Burkhart, W. G., Commonwealth Edison Co., Chicago, Ill.
Burnett, N. O., N. Y. & Queens Electric Light & Power Co., Flushing, N. Y.
Burns, A. F., Bell Telephone Laboratories, Inc., New York, N. Y.
Burrier, E. R., (Member), Hudson Coal Co., Scranton, Pa.
Bushman, A. K., (Member), General Electric Co., Chicago, Ill.
Busteed, J. R., American Tel. & Tel. Co., New York, N. Y.
Byrne, J. A., Troy Gas Co., North Troy, N. Y.
Callow, C. A., Utah Power & Light Co., Grace, Idaho
Camp, G. B., Arctic Dairy Products Co., Detroit, Mich.
Campbell, A. H., Madras Hotel, Portland, Ore.
Caradonna, V., New York Edison Co., New York, N. Y.
Carlson, E., Jr., Stone & Webster, Inc., Boston, Mass.
Carr, C. C., Bell Telephone Laboratories, Inc., New York, N. Y.
(Applicant for re-election)
Caskin, J. M., Danvers Electric Light Dept., Danvers, Mass.
Caywood, R. E., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Cedillo, J. (Member), Mexican Railway Co., Maltrata, Vera Cruz., Mex.
Chandler, M., Commonwealth Power Co., Jackson, Mich.
Chapin, R. I., Crocker McElwain Co., Holyoke, Mass.
Churchill, T. C., Bell Telephone Co. of Canada, Toronto, Ont., Can.
Clark, H. H., Ohio Public Co., Lorain, Ohio
Clark, R. F., Edison Elec. Illuminating Co. of Boston, Boston, Mass.
Clark, S. W., Consulting Engineer, Mexico, D. F., Mex.
Clarke, H. A., Meter Dept., City of Norwich, Norwich, Conn.
Clarke, P., So. New England Telephone Co., New Haven, Conn.
Clifford, C. J., U. S. Coast & Geodetic Survey, Washington, D. C.
Cole, C. C., Duquesne Light Co., Pittsburgh, Pa.
Coley, J., New York Edison Co., New York, N. Y.
Combs, C. R., Omar-Schaefer Electric Co., Detroit. Mich.
Contino, N., Public Service Electric & Gas Co., Irvington, N. J.
Conway, J. T., Murrie & Co., New York, N. Y.
Cook, John W., A. T. & S. F. R. R. Co., Topeka, Kans.
Coram, R. E., (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Corby, E., General Electric Co., Bridgeport, Conn.
Cook, H. S., Cia. Cubana de Electricidad, Inc., Sancti-Spiritus, Cuba
Coultrip, R. L., Fausteel Products Co., Inc., N. Chicago, Ill.
Crabtree, T. H., Bell Telephone Laboratories, Inc., New York, N. Y.
Crosby, R. A., Los Angeles Gas & Electric Corp., Los Angeles, Calif.
Dahl, H. A., Bell Telephone Laboratories, Inc., New York, N. Y.
Dahl, J. F., Bell Telephone Laboratories, Inc., New York, N. Y.
Daley, J. J., Murrie & Co., New York, N. Y.
Davis, C. F., Jr., General Electric Co., Schenectady, N. Y.
Davis, J. A., Automatic Electric Co., Chicago, Ill.
Day, J. F., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Daymude, E. L., Puget Sound Power & Light Co., Portland, Ore.
Dean, H. C., Brooklyn Edison Co., Inc., Brooklyn, N. Y.
de Bernard, E., Compania Cubana de Electricidad, Inc., Matanzas, Cuba
Degner, L. A., Industrial Controller Co., Milwaukee, Wis.
De Graw, H., Louis Kalisher, Inc., Brooklyn, N. Y.
de Savoye, L. A., Brooklyn Edison Co., Brooklyn, N. Y.
Dewey, G. H., General Electric Co., Schenectady, N. Y.
Dickinson, A. G., Consolidated Mining & Smelting Co., Trail, B. C., Can.
Dietz, H. W., Auto Specialties Co., Inc., Elkhart, Ind.
Dittwe, G. R., Pacific Gas & Electric Co., San Francisco, Calif.
Dolarea, O. M., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Dowling, R. C., Wisconsin Telephone Co., Milwaukee, Wis.
Downing, W. C., Jr., Yale University, New Haven, Conn.
Dreyer, W. C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Dugger, P. K., Chief Engineer, Farmville, Va.
Dunn, B. J., Victor X-Ray Corp. of Texas, Dallas, Texas
Ebert, H., Canadian General Electric Co., Toronto, Ont., Can.
Ehrke, L. F., Westinghouse Lamp Co., Bloomfield, N. J.
Ellis, F. A., University of Toronto, Toronto, Ont., Can.
Ensor, J. S., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Erwin, E. L., Bell Telephone Laboratories, Inc., New York, N. Y.
Essig, C. H., Pacific Gas & Electric Co., San Francisco, Calif.
Etkin, H. A., General Electric Co., West Philadelphia, Pa.
Everett, W. J., Cia. Cubana de Electricidad, Inc., Cienfuegos, Cuba
Farnham, C., Schweitzer & Conrad, Inc., Los Angeles, Calif.
Fidler, I., Stehli Silks Corp., New York, N. Y.
Finkelstein, L. M., International Harvester Co., Chicago, Ill.
Finkenstein, A., General Electric Co., New Haven, Conn.
Fitz-Gerald, M. C., Pacific Tel. & Tel. Co., San Francisco, Calif.
Fitzgerald, W. F., Chicago Surface Lines, Chicago, Ill.
Floyd, R. E., Pacific Power & Light Co., Lewiston, Idaho
Flynn, J. A., Interborough Rapid Transit Co., New York, N. Y.
Forbes, L. N., No. Indiana Gas & Electric Co., Hammond, Ind.
Ford, W. F., Union Gas & Electric Co., Cincinnati, Ohio
Freedman, E. A., New York Central Railroad Co., New York, N. Y.
French, B. V., American Bosch Magneto Corp., Springfield, Mass.
Fruchtman, M., Metropolitan Electric Co., Long Island City, N. Y.
Gallup, W. G., Lake Shore Electric Railway, Bay Village, Ohio
Gamboa, C. F., Cia. Cubana de Electricidad, Inc., Station Clara, Cuba
Gannon, J. T., Brooklyn Edison Co., Brooklyn, N. Y.
Gerard, H., Public Service Co. of No. Illinois, Kankakee, Ill.
Gerhart, P. L., Electrical Testing Laboratories, New York, N. Y.
Geymer, H. H., Armour Institute of Technology, Chicago, Ill.
Giersch, O. L., General Electric Co., Schenectady, N. Y.
Gilchrist, J. M., Empire Gas & Electric Co., Auburn, N. Y.
Gillen, G., Pennsylvania Power & Light Co., Hauto, Pa.
Girault, M., General Electric S. A., Mexico D. F., Mex.
Goddard, E. J., Pennsylvania Railroad, Long Island City, N. Y.
Godfrey, H. L., Howson & Howson, Philadelphia, Pa.
Goldsworthy, T. H., Portland Electric Power Co., Portland, Ore.
Goodwin, S., Brooklyn Edison Co., Brooklyn, N. Y.
Graham, A., Postal Tel. & Commercial Cable Co., New York, N. Y.
Graham, R. C., Bartholomew & Montgomery, Vancouver, B. C.
Granich, A. M. (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Gray, E. V., Pratt Institute, Brooklyn, N. Y.
Gray, F. R., Murrie Engineering Co., New York, N. Y.
Gray, R. H., Foreman Electrician, City of Los Angeles, Los Angeles, Calif.
Greene, O. W., Jr., General Electric Co., Pittsfield, Mass.
Greenwald, R. C., Murrie & Co., Inc., New York, N. Y.
Greer, L., General Electric Co., Lynn, Mass.
Griffin, G. A., Union Gas & Electric Co., Cincinnati, Ohio
Gruenberg, A. R., with W. T. Swoyer Co., Johnson City, Tenn.
Gussett, N. B., San Antonio Public Service Co., San Antonio, Texas
Gustafson, H. M., General Electric Co., Seattle, Wash.
Hadley, P. T., General Electric Co., Schenectady, N. Y.
Halloran, D., New York & Queens Elec. Lt. & Pr. Co., Flushing, N. Y.
Halpin, L. C., A. P. & L. Corp., Glens Falls, N. Y.
Hamilton, W. R., West Penn Power Co., Pittsburgh, Pa.
Hamke, J. C., Aluminum Co. of America, Niagara Falls, N. Y.
Harris, H. R., Detroit Edison Co., Connors Creek Plant, Detroit, Mich.

Harrison, C. A., Public Service Co. of Colorado, Denver, Colo.
Hart, W. J., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Hatch, P. M., The Connecticut Co., New London, Conn.
Hausman, S. I. R., Nelson Co., Newark, N. J.
Haw, C. H., New York Edison Co., New York, N. Y.
Hazlett, H. M., U. S. Bureau of Reclamation, Rupert, Idaho
Hearding, W. S., Brooklyn Edison Co., Brooklyn, N. Y.
Helpbringer, J. N., (Fellow), Staten Island Edison Co., Staten Island, N. Y.
Hendrickson, O. F., Pratt Institute, Brooklyn, N. Y.
Herbers, H. H. W., New York Edison Co., Astoria, N. Y.
Herrick, G. H., The Ideal Electric & Mfg. Co., Mansfield, Ohio
Hershey, P. J., Western Electric Co., New York, N. Y.
Herskind, C. C., General Electric Co., Schenectady, N. Y.
Hibbeler, A. F., Commonwealth Edison Co., Chicago, Ill.
Hicks, F. T., U. S. Patent Office, Washington, D. C.
Hill, A. S., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Hirsch, C. J., Electrical Engineer, 452 Riverside Drive, New York, N. Y.
Hoffman, N. W., The Milwaukee Elec. Ry. & Light Co., Milwaukee, Wis.
Holborn, F., Hazeltine Corp. Laboratories, Stevens Inst., Hoboken, N. J.
Hooks, J. H., E. L. Phillips & Co., New York, N. Y.
Hotchkiss, F. H., Western Electric Co., New York, N. Y.
Hubbell, F. J., Western Electric Co., Inc., New York, N. Y.
Huggins, L. G., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Hunt, L. A., Smith Robinson & Co., Ltd., Vancouver, B. C.
Huseby, G. E., Western Electric Co., Chicago, Ill.
Hussey, E. O., Alabama Power Co., Tuscaloosa, Ala.
Inman, E. J., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Jacocks, T. B., General Electric Co., Schenectady, N. Y.
Jarvie, J., Kansas City So. Railway Co., Meavener, Okla.
Jatlow, J. L., Conner Crouse Corp., New York, N. Y.
Jeffery, A. G., Bell Telephone Laboratories, Inc., New York, N. Y.
Jewett, U. M., Eastern Connecticut Power Co., Norwich, Conn.
Jimenez, R., General Electric Co., Schenectady, N. Y.
Jockers, F. E., Greenpoint Electric Equipment Co., Brooklyn, N. Y.
Johannessen, V. L., Western Electric Co., Chicago, Ill.
Johnson, R. E., Railroad Commission of Wisconsin, Madison, Wis.
Johnson, V. L., Bell Telephone Laboratories, Inc., New York, N. Y.
Johnston, D. F., Bell Telephone Laboratories, Inc., New York, N. Y.
Johnstone, H. H., Cleveland Elec. Illuminating Co., Cleveland, Ohio
Joslin, G. B., Bell Telephone Laboratories, Inc., New York, N. Y.
Kahn, J., Otis Elevator Co., Yonkers, N. Y.
Kaplan, S., General Electric Co., Pittsfield, Mass.
Karsten, E. J., United Light & Power Co., Davenport, Ia.
Keckler, C. W., (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Keeton, T. E., Cia. Cubana de Electricidad, Inc., Cienfuegos, Cuba
Kemp, M. V., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Keoughan, L. M., Duquesne Light Co., Pittsburgh, Pa.
Kepp, K., Puget Sound Power & Light Co., Seattle, Wash.
Kershner, V. H., Oklahoma Gas & Electric Co., Muskogee, Okla.
Kietzmann, E. H., Beloit Water, Gas & Electric Co., Beloit, Wis.
King, C. W., Union Gas & Electric Co., Cincinnati, Ohio
Kinney, A. A., Murrie & Co., New York, N. Y.
Kirchner, B. J., Western Electric Co., Inc., New York, N. Y.
Kirk, D., Ware Radio Corp., New York, N. Y.
Kissell, A. L., School of Engg. of Milwaukee, Milwaukee, Wis.
Koch, E. L., Kellogg Switchboard & Supply Co., Chicago, Ill.
Kooistra, L. F., Babcock & Wilcox Co., Bayonne, N. J.
Kopp, O. H., (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
(Applicant for re-election)
Kristan, P., Jr., Brooklyn Manhattan Transit Co., Brooklyn, N. Y.
Krupy, A. J., Commonwealth Edison Co., Chicago, Ill.
Kuelling, V. A., Marko Storage Battery Co., Brooklyn, N. Y.
Kunef, C. T., Fort Humphreys, Va.
Kurtz, E. K., Edison Electric Co., Lancaster, Pa.
La Forge, C., Murrie Engineering Co., New York, N. Y.
Lamb, J. F., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Landau, M., Bureau of Pr. & Lt., City of Los Angeles, Los Angeles, Calif.
Langman, J. D., Langman Electric & Mach. Co., Portland, Ore.
Langworthy, R. S., United Electric Light & Power Co., New York, N. Y.
Larner, R. A., Texas Power & Light Co., Dallas, Texas
Lawthers, S. M., Union Switch & Signal Co., Swissvale, Pa.
Ley, H. S., East Penn Electric Co., Pottsville, Pa.
Lindvall, I., Adirondack Power & Light Corp., Schenectady, N. Y.
Litchfield, H. S., Blackstone Valley Gas & Electric Co., Pawtucket, R. I.
Little, F. G., Home Tel. & Tel. Co. of Pasadena, Pasadena, Calif.
Locher, L. L., General Electric Co., Schenectady, N. Y.
Long, G. A., Jr., General Electric Co., Schenectady, N. Y.
Ludlow, M. O., Pacific Gas & Electric Co., Antioch, Calif.
Lundius, E. R., Bell Telephone Laboratories, Inc., New York, N. Y.
MacLaren, R. P., Bell Telephone Laboratories, Inc., New York, N. Y.
Mader, C. E., Lewis Institute, Chicago, Ill.
Maloney, J. I., Bell Telephone Co. of Pa., Philadelphia, Pa.
Mallett, M. B., General Electric Co., Pittsfield, Mass.
Maltby, C. W., So. California Tel. Co., Los Angeles, Calif.
Margiotts, G., New York Edison Co., New York, N. Y.
Marousek, G., W. A. Wieboldt & Co., Chicago, Ill.
Marsteller, G. F., C. H. Tenney & Co., Boston, Mass.
(Applicant for re-election)
Martin, J. J., Wagner Electric Corp., Chicago, Ill.
Martin, T. G., (Fellow), Automatic Electric Co., Inc., Chicago, Ill.
Martin, W. H., General Electric Co., Schenectady, N. Y.
Marting, H. E., (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
(Applicant for re-election)
Mason, M. A., Los Angeles Gas & Electric Corp., Los Angeles, Calif.
Mathison, K. V., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Matson, T. M., with F. G. Baum, Cassel via Redding, Calif.
Maus, T. J., Commonwealth Edison Co., Chicago, Ill.
Maxwell, M. V., Westinghouse Elec. & Mfg. Co., Wilkinsburg, Pa.
Mazak, J., Jr., Western Electric Co., Inc., Philadelphia, Pa.
McCandless, C. F., Consumers Power Co., Muskegon, Mich.
McCauley, C., Jr., 32 Wool St., San Francisco, Calif.
McClellan, B. A., Hudson Motor Car Co., Detroit, Mich.
McDaniel, O. S., Southwestern Bell Tel. Co., St. Louis, Mo.
McDougall, J. B., Interborough Rapid Transit Co., New York, N. Y.
McIntire, M. M., Merced Irrigation District, Exchequer, Calif.
McKechnie, J. D., Charles H. Tenney & Co., Boston, Mass.
McNally, J. O., Bell Telephone Laboratories, Inc., New York, N. Y.
McNicol, F. C., Industrial Controller Co., Milwaukee, Wis.
Meadows, J. J., New York Central Railroad Co., New York, N. Y.
Meeks, J. R., Westinghouse Elec. & Mfg. Co., New York, N. Y.
Meiers, W. W., New York Central Railroad Co., New York, N. Y.
Meserve, W. E., University of Maine, Orono, Me.
Methfessel, C. W., Commonwealth Power Corp., Jackson, Mich.
Metzner, H. A., Interborough Rapid Transit Co., New York, N. Y.
Michelsen, J. H., Pacific Tel. & Tel. Co., Sacramento, Calif.
Miller, G. W., Rochester Telephone Corp., Rochester, N. Y.
Minnich, J. W., Pennsylvania Power & Light Co., Hazleton, Pa.
Mizell, M. H., Lieut. U. S. Marine Corps, Washington, D. C.
Moellendick, K. F., L. A. Automotive Works, Los Angeles, Calif.
Montemurro, M. M., Hydro-Electric Power Commission, Toronto, Ont., Can.
Morrison, J. J., American Steel & Wire Co., Worcester, Mass.
Mulford, V. A., American Gas & Electric Co., New York, N. Y.
Mundy, T. V., Public Service Production Co., Kearny, N. J.
Myers, L. E., Pennsylvania Power & Light Co., Hazleton, Pa.
Nardi, M., Commonwealth Power Corp., Jackson, Mich.
Neifert, J. O., Pennsylvania Power & Light Co., Hauto, Pa.
Nock, H. K., Newburyport Gas & Electric Co., Newburyport, Mass.
Norlander, S. G. S., Adirondack Power & Light Corp., Schenectady, N. Y.
Norman, G. H. C., Consolidated Mining & Smelting Co., Trail, B. C.
North, C. S., Supervisor of Constr., Mrs. M. North, Newport, R. I.
O'Connell, M. J., Pennsylvania Power & Light Co., Hauto, Pa.
Oliver, C. J., Canadian National Electric Railways, Toronto, Ont., Can.
Oliver, C. N., New Orleans Public Service Co., Inc., New Orleans, La.
Olsen, H. A., Pacific Tel. & Tel. Co., San Francisco, Calif.
O'Neil, T. J., Bell Telephone Laboratories, Inc., New York, N. Y.
Paige, J. H., with W. E. Langstaff, Pasadena, Calif.
Paine, L. A., (Member), Lincoln Meter Co., Toronto, Ont., Can.
(Applicant for re-election)

Palmer, E. L., Pennsylvania Power & Light Co., Allentown, Pa.
Parker, C. N., Southern Sierras Power Co., Riverside, Calif.
Parker, L. W., (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Parnell, W. S., The Canadian Crocker-Wheeler Co., Ltd., St. Catharines, Ont., Can.
Paxton, R., General Electric Co., Schenectady, N. Y.
Pedersen, L. E., Bell Telephone Laboratories, Inc., New York, N. Y.
Pennell, S. B., New York Central Railroad Co., New York, N. Y.
Percy, J. P., Compania Azucarera Arroyo Blanco, Maceo, Oriente, Cuba
Perring, R. B., (Member), Hydro-Electric System, East York, Toronto, Ont., Can.
Peters, J. C., Jr., Leeds & Northrup Co., Philadelphia, Pa.
Peters, J. R., City Light Dept., Seattle, Wash.
Peters, R. C., Westinghouse Elec. & Mfg. Co., Buffalo, N. Y.
Peterson, D. M., Ohio Brass Co., Los Angeles, Calif.
Phillips, C. F., Mechanics Institute, Rochester, N. Y.
Plant, P. R., New York Central Railroad, New York, N. Y.
Plass, R. B., Westinghouse Elec. & Mfg. Co., San Francisco, Calif.
Plotner, L. D., (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Ports, E. G., Bell Telephone Laboratories, Inc., New York, N. Y.
Prangley, A. G., Jr., 28 Division St., Schenectady, N. Y.
Premo, J. G., Jr., Commonwealth Power Corp., Jackson, Mich.
Prieto, A. I., Stevens Institute of Technology, Hoboken, N. J.
Prior, W. J., Los Angeles Gas & Electric Co., Los Angeles, Calif.
Pritchard, E. O., Bell Telephone Laboratories, Inc., New York, N. Y.
Raab, H. J., Chas. Cory & Son, Inc., San Francisco, Calif.
Randolph, L. S., New York Central Railroad Co., New York, N. Y.
Reese, L., Jr., Pacific Gas & Electric Co., Modesto, Calif.
Reichard, W. H., (Member), General Railway Signal Co., Rochester, N. Y.
Remington, A. E., City Light Dept., City of Seattle, Seattle, Wash.
Rhodes, R. S., New York Central Railroad Co., New York, N. Y.
Richards, D., Pennsylvania Power & Light Co., Hauto, Pa.
Robertson, B. L., University of Michigan, Ann Arbor, Mich.
Robertson, E. P., Detroit Edison Co., Detroit, Mich.
Robinson, C. R., Bell Telephone Laboratories, Inc., New York, N. Y.
Robinson, H. I., Postal Telegraph Co., New York, N. Y.
Rojas, J. G., General Electric Co., Schenectady, N. Y.
Rolfe, J. T., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Rounds, T. E., Jr., New York Central Railroad Co., New York, N. Y.
Rumrill, H., General Electric Co., West Lynn, Mass.
Ruppenthal, F. W., Jr., Western Electric Co., Inc., Philadelphia, Pa.
Rush, S. E., Union Gas & Electric Co., Cincinnati, Ohio
Russell, R. H., Western Electric Co., Chicago, Ill.
Saliger, H. F., So. California Edison Co., Los Angeles, Calif.
Samson, D. F., Electrical Contracting, Branford, Conn.
Savage, E., American Can Co., Portland, Ore.
Schaefer, J. H., New York Telephone Co., Albany, N. Y. (Applicant for re-election)
Schahfer, R. M., Northern States Gas & Electric Co., Hammond, Ind.
Schnautz, W. J., New York Telephone Co., Buffalo, N. Y.
Schnurr, F. E., Murrie & Co., New York, N. Y.
Scholz, C. B., Interstate Utilities Co., Spokane, Wash.
Schrum, M. O., Bell Telephone Laboratories, Inc., New York, N. Y.
Seese, R. St. C., Western Electric Co., Detroit, Mich.
Seiple, W. M., Pennsylvania Power & Light Co., Wilkes-Barre, Pa.
Shelhorse, A. W., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Shepherd, D. H., New York Telephone Co. New York, N. Y.
Shiley, S. W., (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Shiroyan, H. K., American Brass Co., Hastings-on-Hudson, N. Y.
Simmons, R. J., Fairbanks-Morse Elec. Mfg. Co., Indianapolis, Ind.
Simon, H. O., Western Electric Co., Chicago, Ill.
Simpson, P. H., Gould Coupler Co., New York, N. Y.
Skroder, C. E., University of Illinois, Urbana, Ill.
Slater, F. R., Oregon Agricultural College, Corvallis, Ore.
Sogge, R. C., General Electric Co., Schenectady, N. Y.
Soderberg, E. W., Pacific Gas & Electric Co., San Francisco, Calif.
Sovitzky, W. V., Pawling & Harnischgeger Co., Milwaukee, Wis.
Spaulding, J. N., Great Western Power Co., San Francisco, Calif.
Spicer, F. O., Radio Corp. of America, New York, N. Y.
Spring, E. W., The Detroit Edison Co., Detroit, Mich.
Standish, G., Bronx Gas & Electric Co., New York, N. Y.
Stastny, J. F., International Harvester Co., Chicago, Ill.
Steward, H. R., East Penn. Electric Co., Pottsville, Pa.
Stewart, A. W. J., Toronto Hydro-Electric System, Toronto, Ont., Can.
Stewart, H. R., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Stone, E. G., Mt. Shasta Power Corp., Cassel, Calif.
Stubbs, W. W., Middletown Auto-Elec. Service Co., Hamilton, Ohio
Sykes, P. M., 1510 S. Center St., Terre Haute, Ind.
Syler, R. E., Mountain States Tel. & Tel. Co., Denver, Colo.
Tang, K. Y., Ohio State University, Columbus, Ohio
Tate, W. Mexicana Railroad, Maltrata, Vera Cruz, Mex.
Teague, J. A., Baker Iron Works, Los Angeles, Calif.
Tecklenburg, H. C., N. Y. & Queens Elec. Lt. & Pr. Co., Flushing, N. Y.
Terry, D. M., Bell Telephone Laboratories, Inc., New York, N Y.
Thielman, J. A., Philadelphia Electric Co., Philadelphia, Pa.
Thomas, J. W., Johns Hopkins University, Baltimore, Md.
Thomas, O. J., Pennsylvania Power & Light Co., Hazleton, Pa.
Thompson, A. J., The Pacific Tel. & Tel. Co., San Francisco, Calif.
Thompson, A. W., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Thorud, E., Adirondack Power & Light Corp., Schenectady, N. Y.
Tinkey, O. G., Ideal Electric Co., Urbana, Ill. (Applicant for re-election)
Tomlinson, F. R., General Electric Co., Cleveland, Ohio
Tousey, C. H., The Detroit Edison Co., Detroit, Mich.
Towers, R. A., Metro-Goldwyn-Mayer Corp., Culver City, Calif.
Tracy, H. H., Oregon Short Line Railroad Co., Pocatello, Idaho
Troy, J. R., Murrie & Co., New York, N. Y.
True, J. G., Tampa Electric Co., Tampa, Fla.
Tucker, R. S., American Tel. & Tel. Co., New York, N. Y.
Tudor, R. DuB., Western Electric Co., Denver, Colo.
Tuttle, C. M., General Electric Co., Bridgeport, Conn.
Underhill, W. L. L., British Columbia Electric Rwy. Co., Coglan, B. C.
Utter, R. E., Union Gas & Electric Co., Cincinnati, Ohio
Vaclavik, F. J., Commonwealth Power Corp., Jackson, Mich.
Valentine, C. W., Westinghouse Elec. & Mfg. Co., New York, N. Y.
Van Wyk, H., Puget Sound Power & Light Co., Seattle, Wash.
Velasco, L. R., Mexican Railroad Co., Vera Cruz, Mex.
Vickers, H., (Member), University of British Columbia, Vancouver, B. C.
Vogelsang, L. O., San Antonia Public Service Co., San Antonia, Texas
Voss, H. M., So. California Telephone Co., Los Angeles, Calif.
Wadsley, C. R., Bell Telephone Laboratories, Inc., New York, N. Y.
Waite, R. T., Aetna Life Insurance Co., Hartford, Conn.
Waligaski, A. A., Western Electric Co., Chicago, Ill.
Walker, J. J. R., Western Electric Co., New York, N. Y.
Walker, S. W., Canadian National Railways, Toronto, Ont., Can.
Webb, W. R., Worthington Pump & Machinery Corp., Elmwood Place, Ohio
Weber, C. W., Licensed Electrical Contractor, New York, N. Y.
Weiner, W., Pennsylvania Railroad Co., Long Island City, N. Y.
Westin, C. H., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Williams, A. T., Newfoundland Power & Paper Co., Ltd., Deer Lake, N. F.
Williams, F. A., Western Electric Co., New York, N. Y.
Williams, S. R., Westinghouse Elec. & Mfg. Co., South Bend, Ind.
Wills, A. L., General Electric Co., St. Louis, Mo.
Withrow, C. H., Bell Telephone Laboratories, Inc., New York, N. Y.
Wurth, C. G., Western Electric Co., Inc., New York, N. Y.
Yarmack, J. E., Yale University, New Haven, Conn.
York, F. J., Frank J. York Co., Detroit, Mich.
Zimmerman, J. A., (Member), Chas. H. Tenney & Co., Boston, Mass.
Zucco, J. J., New York Edison Co., New York, N. Y.

Total 433

Foreign

Chernyshoff, A., (Fellow), Leningrad Polytechnic Inst., Sosnowka, Leningrad, Russia (Applicant for re-election)
de Oliveira, V., Compagnia Luz Electrica de Amargosa, Amargosa, Bahia, Brazil, S. A.
Doyle, J. T., Westport Stockton Coal Co., Ngakawau, Westport, New Zealand
Gibson, H. J., British Electric Federation, Ltd., London, W. C. 2, Eng.
Harvey, A. F., (Member), Central Argentine Railway, Victoria, F. C. C. A., Argentina, S. A.
Inouye, R., Hitachi Engineering Works, Sukegawa Ibarakiken, Japan

Langlois, R., Ateliers de Constr. Electriqie de Jeumont, Jeumont, Nord, France
Ono, Y., Shibaura Engineering Works, Shibaku, Tokyo, Japan
Seki, Y., Mitsubishi Electrical Engineering Co., Nagasaki, Japan
Sreenivasan, K., Indian Institute of Science, Bangalore, Ind.
Willison, J. W., (Member), Yorkshire Electric Power Co., Leeds, Yorkshire, Eng.
Zeplaier, P. P., Polytechnic Institute of Leningrad, Leningrad, Russia
Total 12

STUDENTS ENROLLED DECEMBER 10, 1925

Achenbach, Jay Oswald, Cornell Univ.
Adams, Hampton C., Univ. of Ky.
Allen, Lesler E., University of Kansas
Allen, William B. C., Yale Univ.
Alvarado, Everardo M., Milwaukee School ofE ngg.
Anders, Russell D., Penn. State College
Andriacchi, Louis A. Marquette Univ.
Arehart, Narbin E., U. of Notre Dame
Askey, Russel O., Univ. of Ill.
Babcock, John W., University of Nevada
Barshewski, Francis A. Mil. School of Engg.
Batchelor, Harold, Kans. St. Agri. College
Bauer, Lawrence J., State College of Washington
Baur, Roy E., Armour Inst.
Beckman, Clifford A., Armour Inst.
Bell, Delamar T., Ga. School of Tech.
Bellaschi, Peter L., Mass. Inst. of Technology
Benner, Philip E., Iowa State College
Benson, Arnold, University of Nevada
Bergstrom, Francis A., Ore. Inst. of Tech.
Bernhard, Carl W. H., University of Wash.
Beth, Richard A., Worcester Poly. Inst.
Bishop, Charles B., Univ. of British Columbia
Bliss, Donald S., Worcester Poly. Inst.
Bostwick, Myron A., State College of Washington
Bower, Marcy J., Univ. of Delaware
Bowyer, Dee, Kansas State Agri. College
Boyd, Spencer W., Georgia School of Tech.
Boyle, Stanley C., Univ. of Notre Dame
Brandt, R. T., Case School Appl. Science
Braunsdorf, Joseph A., Univ. of Notre Dame
Breen, Raymond K., Notre Dame Univ.
Bretschneider, Max E., Northeastern Univ.
Brewster, Oliver H., Worcester Poly. Institute
Brooks, Gerald, E., Okla. Agri. & Mech. College
Brown, Arthur R., Worcester Poly. Inst.
Brown, Paul M., University of Colorado
Brumbaugh, Claude J., Case School Applied Science
Buchanan, Thomas G., University of British Columbia
Bundy, C. Le Grand, Cornell University
Bunte, Herman C., Kansas State College
Burchfield, Clinton, R., Penn., State College
Burcky, Charles W., Armour Inst.
Burns, Leroy H., Yale Univ.
Burton, Raymond E., Kansas State Agri. College
Calder, Donald A., Worcester Poly. Inst.
Camelio, John F., Northeastern Univ.
Capodanno, Rocco J., Univ. of Illinois
Capouch, Charles, Jr., Armour Inst.
Carlson, John L., University of Nevada
Carpenter, Harry B., Jr., Univ. of Ky.
Cartwright, P. Marquette Univ.
Castor, Thomas D., University of Wash.
Chase, William C., Rensselaer Poly. Institute
Chepoorin, Nicholas J., University of Cincinnati
Christie, Wilfred J., Armour Inst.
Churchill, A. E., Kansas State Agri. College
Conklin, James Wolf, Cornell Univ.
Conrad, Irving F., Purdue Univ.
Conway, George J., Mass. Inst. of Technology
Cook, Edwin E., Ga. School of Tech.
Coole, G. Edwin, Armour Inst.
Copans, William J., Northeastern Univ.
Crofts, Elmer B., Case School Appl. Science
Cuneo, F. N., Yale Univ.
Dam, Cyrus K., Univ. of Nevada
Daniels, Erving, Ore. Inst. of Tech.
Danstedt, Rudolph T., Worcester Poly. Inst.
Darnell, Thomas H., Mass. Inst. of Technology
Davidson, John W., Yale Univ.
Day, Cortez, Univ. of Kentucky
Demeter, Julius, Rutgers University
Denison, Harold M., Kansas St. Agri. College
Dioguardi, Paul J., Brooklyn Poly. Inst.
Donogne, T. F., Univ. of Notre Dame
Doohen, Will, Univ. of So. Dakota
Dougherty, Patrick J., Marquette Univ.
Drexler, Elmer W., Case School Appl. Science
Drugg, A. Burbank, Worcester Poly. Inst.
Dunham, S. Vene., Armour Inst.
Edwards, M. A., Kansas St. Agri. College
Eisenberg, Julius G., Armour Inst.
Elliot, Earl R., Purdue University
Elwell, Maynard, Northeastern University
Erickson, John C., Case School Appl. Science
Esenwein, August C., Jr., Yale Univ.
Ewald, Fred J., Jr., Armour Inst.
Faber, Roger N., Northeastern Univ.
Farrant, George A., Univ. of Kentucky
Fielder, Frederick D., Worcester Poly. Inst.
Finch, Irving, Jr., Cornell Univ.
Finlayson, Kenneth M., Worcester Poly. Inst.
Fisher, L. C., Purdue University
Flenner, Aetley C., Armour Inst.
Fligg, James A., University of Kansas
Fogarty, Edward J., Yale Univ.
Foley, Melville, J., Jr., Ore. Inst. of Tech.
Foley, Robert J., Worcester Poly. Inst.
Frankel, Charles S., Armour Inst.
Freisleben, Wenrorth H., Milwaukee School of Engg.
Gilbert, Franklyn C., Yale Univ.
Gill, Otto H., Univ. of British Columbia
Glennan, T. Keith, Yale Univ.
Glick, John A., Cornell Univ.
Goldben, Isadore, Univ. of Ky.
Goldman, Abraham S., New York Univ.
Gossman, Lew Z., Purdue Univ.
Greene, Richard H., Univ. of Notre Dame
Greenstein, Philip, New York Univ.
Gremillion, Bichat X., Univ. of Notre Dame
Haas, Sam C., Okla. A. & M. College
Hahn, Alvin W., Case School Appl. Science
Halet, Ahmed H., Mass. Inst. of Technology
Hansen, Marion O., Montana State College
Hanson, Walter I., Armour Inst.
Harless, Charles M., Rice Inst.
Harmon, J. Clayton, Univ. of Illinois
Harris, Lawrence, Poly. Inst. of Brooklyn
Harrod, Robert H., Univ. of Kentucky
Hastings, Gerald M., Yale Univ.
Hathaway, Claude Macy, Univ of Colorado
Heckman, George J., Worcester Poly. Inst.
Heft, Merrill, Ohio Northern Univ.
Hefty Herman, New York Univ.
Heitmeyer, Paul R., Ore. Inst. of Tech.
Hensel, Marion L., Colorado Univ.
Hinkley, James W., 3rd., Yale Univ.
Hinman, Wilbur S., Jr., Virginia Military Inst.
Hitchcock, Norman P., Case School Appl. Science
Hodik, Frank, Milwaukee School of Engg.
Hogan, Bernard T., Armour Inst.
Hollingsworth, F. H., Purdue University
Hollins, Fred. G., Rice Institute
Holmes, D. W., Iowa State College
Horan, Joseph J., Univ. of Notre Dame
Houlihan, Richard P., Worcester Poly. Inst.
Howell, Clifford A., New York Univ.
Hoyer, Henry E., Univ. of S. Dakota
Hummel, Carl C., University of Cincinnati
Jackson, Lloyd R., Univ. of Colorado
Jamison, John S., Jr., Virginia Military Inst.
Johannessen, Raymond, New York Univ.
Johnson, Dan A., Washington State College
Johnson, Mark F., Milwaukee School of Engineering
Jones, William L., Clemson College
Jones, William W., Milwaukee School of Engg.
Joslin, Edward, Univ. of Wyo.
Juuti, William, Armour Inst.
Kanke, Charles H., Worcester Poly. Inst.
Kasher, Raymond J., Univ. of Notre Dame
Khoo, Robert Y., Univ. of Notre Dame
Kiely, Harold J., Univ. of Notre Dame
King, Donald L., Worcester Poly. Inst.
King, Hamilton W., Worcester Poly. Inst.
Kistler, John F., University of North Carolina
Klimeck, Francis, Milwaukee School of Engg.
Knaus, Malcolm F., Univ. of Notre Dame
Kostash, Elias L., Milwaukee School of Engg.
Kremser, Albert W., Marquette Univ.
Lacerte, O. J., Kansas State Agri. College
Lanphier, Robert C., Jr., Yale Univ.
Larsen, Lloyd, University of Wash.
Laquidara, Antonio K., New York Univ.
La Salle, W. M., Purdue Univ.
Laupp, Charles N., Marquette Univ.
Leatherman, H. Ardene, Cornell University
Levine, Victor A., Yale Univ.
Lindersmith, Paul M., Ohio Northern Univ.
Lisle, Claiborne, Univ. of Kentucky
Lockwood, Edwin H., Jr., Yale Univ.
Loeb, Frederic, W., Armour Inst.
Loeffler, Bernard T., Univ. of Notre Dame
Long, Loraine C., Kansas University
Lowe, Walter E., Univ. of Tenn.
Lyon, Dean A., Cornell Univ.
Mackey, Theodore, Lehigh University
Madden, Edwin H., Armour Inst.
Malloy, Robert O., Univ. of Kentucky
Mann, William H., Jr., University of Arkansas
Mason, Charles E., Univ. of Notre Dame
Mather, Thomas T., Drexel Institute
Mathewson, Philip L., Univ. of British Columbia
McCoy, Julius C., Univ. of Notre Dame
McDonnell, John F., Univ. of Mich.
McGillicuddy, Eugene J., Worcester Poly. Inst.
McPhee, Howard S., Univ. of Maine
Merrill, Dean L., Worcester Poly. Inst.
Metcalfe, Laurence, Virginia Military Inst.
Miller, Albert B., Milwaukee School Engg.
Moauro, Joseph S., Northeastern University
Moore, Wilbur A., Union College
Morgan, M. G., Armour Inst.
Muluihill, Thomas A., Marquette Univ.
Nelson, William A., Kansas State Agri. College
Neville, Jesse O., Virginia Military Inst.
Newton, David A., Univ. of Kentucky
Nordbrock, Raymond, Armour Inst.
North, John T., Jr., Univ. of Br. Columbia
Northrop, Russell O., Milwaukee School of Engg.
Nye, Victor C., Milwaukee School of Engg.
O'Dwyer, John M., Colorado University
Olson, Lynn R., University of Nevada
O'Neill, Daniel J., Univ. of Notre Dame
Osborne, Samuel C., Cornell Univ.
Owen, Stanley Z., Purdue Univ.
Paltz, Walter J., Univ. of Notre Dame
Parker, William W., Yale, Univ.
Parsons, Delmont, University of Maine
Perry, William J., Worcester Poly. Inst.
Peterson, Carl H., Mass. Inst. of Technology
Peterson, Lawrence S., Worcester Poly. Inst.
Picking, J. W., Lehigh Univ.
Pischke, Frank J., Armour Inst.
Polk, Orval H., University of Colorado
Ptacek, John E., Jr., Case School Appl. Science
Purcell, Edward J., Jr., Worcester Poly. Inst.
Raffone, William P., Northeastern Univ.
Ramm, John B., University of Wash.
Randall, Gerald A., Case School Appl. Science
Rapley, William J., New York University
Rathbun, Harold V., Kansas State College
Reeder, Wilson F., Case School Appl. Science
Reupke, Albert A., Univ. of Illinois
Reynolds, James Walter, Univ. of Tenn.
Reynolds, Marshall E., Armour Inst.
Rice, Chester C., Univ. of Kentucky
Richards, Philip A., Washington State College
Riethmiller, Earl R., Univ. of Mich.
Robinson, George R., University of British Columbia
Rue, Albert, Rutgers University
Rusch, Philip W., Univ. of Kentucky
Russell, William A., Jr., Worcester Poly. Inst.
Rutigliano, Dominic, P., New York Univ.
Ryan, Thomas E., Worcester Poly. Inst.
Samson, Emery E., Case School Appl. Science
Sanders, Howard C., Marquette Univ.
Schamel, Clyde H., Univ. of Notre Dame
Schofield, Bernard R., Armour Inst.
Schrier, Donald P., Univ. of Mich.

Schultheis, Leo J., Univ. of Notre Dame
Schumacher, Addison E. W., Cornell Univ.
Shaw, John C., Univ. of N. Dakota
Sheridan, Thomas W., Univ. of Notre Dame
Sherman, Kenneth S., Case School Appl. Science
Sherys, John J., Northeastern University
Short, Howard A., Ore. Inst. of Tech.
Simmonds, Arthur T., Worcester Poly. Inst.
Simpson, Alfred, Univ. of Kentucky
Skelley, Paul L., Univ. of Notre Dame
Smith, George L., Jr., Cornell Univ.
Smith, Herbert H., University of Washington
Solomon, Raymond J., Univ. of Ill.
Somppi, Theodore S., Case School Appl. Science
Spyut, Albert B., Northeastern Univ.
Stahl, Elmer W., Armour Inst.
Starr, Troy S., Municipal U. of Akron, Ohio
Steele, Mabbott B., Worcester Poly. Inst.
Steeneck, W. Robert, New York Univ.
Steensen, Alfred P., Mass. Inst. of Technology
Steffen, Charles L., Marquette Univ.
Stolt, William, Washington State College
Stone, Howard C., Univ. of Washington
Sudduth, Henry N., Yale Univ.
Sullivan, John E., Univ. of Notre Dame
Swanson, Vincent W., Armour Inst.
Swicegood, Harry L., Ga. School of Tech.
Tarbox, Arthur M., Worcester Poly. Inst.
Tarbox, Roger B., Worcester Poly. Inst.
Taylor, Elmer L., Worcester Poly. Inst.
Taylor, Frank, C., Worcester Poly. Inst.
Thacker, William J., Worcester Poly. Inst.
Thierman, Vincent, Univ. of Notre Dame
Thompson, Browder J., University of Wash.
Thorsen, Ewald C., Armour Inst.
Tielking, John W., University of Cincinnati
Tijerino Cesar D., Lehigh University
Tine, Amasa N., Lafayette College
Travis, Irven A., Univ. of British Columbia
Tsu Ye Lu, Mass. Inst. of Technology
Tucker, Wallace H., Worcester Poly. Institute
Valesio, Mario J., New York Univ.
Vines, Alex., Ore. Inst. of Tech.
Von Voigtlander, Frederick, Univ. of Michigan
Wade, Llewellin W., Worcester Poly. Inst.
Waehner, Albert R., Armour Inst.
Wainman, Philip R., Univ. of British Columbia
Watkins, Noble, Univ. of Pittsburgh
Weber, Henry A., New York University
Weinberg, Joe, Armour Inst.
Werden, Arthur C., Jr., California Inst. of Technology
White, Taylor G., Jr., Univ. of Kentucky
Whitehead, Edwin, Univ. of Colorado
Wilcox, Stanley H., Rutgers University
Williams, Charles H., Univ. of Colorado
Williams, Harold R., University of Michigan
Williamson, Richard C., Univ. of Kentucky
Woeltge, Franklin W., University of Illinois
Wolfe, W. F., Purdue University
Wolverton, Charles D., Yale Univ.
Wood, John F., Worcester, Poly. Inst.
Woods, Henry L., Jr., Univ. of Kentucky
Works, Herbert F., Northeastern Univ.
Wright, Marshall E., Univ. of Ky.
Yates, James O., Univ. of Wyo.
Yim, Henry Y., Marquette University
Young, Albert M., Kansas State Agri. College
Young, John E., Drexel Inst.
Young, L. L., Purdue University
Zornik, Anton, Carnegie Tech.

Officers A. I. E. E. 1925-1926

PRESIDENT
(Term expires July 31, 1926)
M. I. PUPIN

JUNIOR PAST PRESIDENTS

(Term expires July 31, 1926) HARRIS J. RYAN
(Term expires July 31, 1927) FARLEY OSGOOD

VICE-PRESIDENTS

(Terms expire July 31, 1926)
HAROLD B. SMITH (District No. 1)
EDWARD BENNETT (District No. 5)
JOHN HARISBERGER (District No. 9)
L. F. MOREHOUSE (District No. 3)
H. W. EALES (District No. 7)

(Terms expire July 31, 1927)
P. M. DOWNING (District No. 8)
HERBERT S. SANDS (District No. 6)
W. E. MITCHELL (District No. 4)
ARTHUR G. PIERCE (District No. 2)
W. P. DOBSON (District No. 10)

MANAGERS

(Terms expire July 31, 1926)
H. M. HOBART
ERNEST LUNN
G. L. KNIGHT

(Terms expire July 31, 1928)
JOHN B. WHITEHEAD
J. M. BRYANT
E. B. MERRIAM

(Terms expire July 31, 1927)
W. M. McCONAHEY
W. K. VANDERPOEL
H. P. CHARLESWORTH

(Terms expire July 31, 1929)
M. M. FOWLER
H. A. KIDDER
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(Terms expire July 31, 1926)
GEORGE A. HAMILTON — F. L. HUTCHINSON

HONORARY SECRETARY
RALPH W. POPE

GENERAL COUNSEL
PARKER & AARON
30 Broad Street, New York

PAST-PRESIDENTS—1884-1925

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
*T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
*ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
*EDWIN J. HOUSTON, 1893-4-5.
*LOUIS DUNCAN, 1895-6-7.
*FRANCIS BACON CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
*CHARLES P. STEINMETZ, 1901-2.
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, 1904-5.
*SCHUYLER SKAATS WHEELER, 1905-6.
*SAMUEL SHELDON, 1906-7.
*HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-9.
LEWIS B. STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13.
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Washington, D. C.	A. F. E. Horn	L. E. Reed, Potomac Elec. Pr. Co., 14th & C Sts., N. W., Washington, D. C.
Worcester	E. T. Harrop	Fred B. Crosby, 15 Belmont St., Worcester, Mass.
Total 50		

LIST OF BRANCHES

Name and Location	Chairman	Secretary
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Alabama, Univ. of, University, Ala.	C. E. Rankin	Sewell St. John
Arizona, Univ. of, Tucson, Ariz.	C. A. Rollins	J. W. Cruse
Arkansas, Univ. of, Fayetteville, Ark.	R. McFarland	J. Demarke
Armour Inst. of Tech., Chicago, Ill.	H. J. Prebensen	W. A. Dean
Brooklyn Poly Inst., Brooklyn, N. Y.	J. C. Arnell	J. H. Diercks
Bucknell Univ., Lewisburg, Pa.	T. J. Miers	C. A. Rosencrans
California Inst. of Tech., Pasadena	W. A. Lewis	A. E. Schueler
California, Univ. of, Berkeley, Calif.	E. A. Fenander	C. F. Dalziel
Carnegie Inst. of Tech., Pittsburgh, Pa.	G. L. LeBaron	H. E. Ashworth
Case School of Applied Science, Cleveland, O.	C. A. Baldwin	A. B. Anderson
Catholic Univ. of America, Washington, D. C.	B. J. Kroeger	J. E. O'Brien
Cincinnati, Univ. of, Cincinnati, O.	F. Sanford	W. C. Osterbrock
Clarkson Coll. of Tech., Potsdam, N.Y.	W. R. MacGregor	L. G. Carney
Clemson Agri. College, Clemson College, S. C.	B. V. Martin	W. H. Sudlow
Colorado State Agri. Coll., Ft. Collins	C. O. Nelson	D. W. Asay
Colorado, Univ. of, Boulder, Colo.	O. V. Miller	L. E. Swedlund
Denver, Univ. of, Denver, Colo.	Earl Reed	R. L. Kuhler
Drexel Institute, Philadelphia, Pa.	E. B. Middleton	W. N. Richards
Florida, Univ. of, Gainesville, Fla.	O. B. Turbyfill	R. Theo. Lundy
Georgia School of Tech., Atlanta, Ga.	S. M. Thomas	C. E. Burke
Idaho, University of, Moscow, Idaho	R. C. Beam	James Gartin
Iowa State College, Ames, Iowa	P. E. Benner	H. J. Bidduloh
Iowa, Univ. of, Iowa City, Iowa	L. Diamond	A. C. Boeke
Kansas State College, Manhattan	H. M. Porter	E. J. Weeks
Kansas, Univ. of, Lawrence, Kans.	L. E. Allen	A. F. Hartung
Kentucky, Univ. of, Lexington, Ky.	J. A. Weingartner	C. E. Albert
Lafayette College, Easton, Pa.	A. H. Gabert	F. G. Keim
Lehigh Univ., S. Bethlehem, Pa.	F. G. Kear	J. H. Shuhart
Lewis Institute, Chicago, Ill.	O. D. Westerberg	R. G. Raymond
Maine, Univ. of, Orono, Me.	S. B. Coleman	H. S. McPhee
Marquette Univ., Milwaukee, Wis.	C. H. Legler	M. J. Smith
Massachusetts Inst. of Tech., Cambridge, Mass.	Stuart John	H. W. Geyer
Michigan State Coll., East Lansing	H. C. Roberts	R. A. Bailey
Michigan, Univ. of, Ann Arbor, Mich.	M. H. Nelson	S. L. Burgwin
Milwaukee Engg. School of, Milwaukee, Wis.	S. A. Moore	B. J. Chromy
Minnesota, Univ. of, Minneapolis	R. L. Christen	A. A. Lee
Missouri, Univ. of, Columbia, Mo.	M. P. Weinbach	L. Spraragen
Missouri School of Mines and Metallurgy, Rolla, Mo.	W. J. Maulder	R. P. Baumgartner
Montana State Coll., Bozeman, Mont.	T. A. Van Noy	J. A. Thaler
Nebraska, Univ. of, Lincoln, Neb.	R. Worrest	C. J. Madsen
Nevada, Univ. of, Reno, Nev.	Lloyd Crosby	R. C. Samuels
New York, College of the City of, New York, N. Y.	J. Wilson	Frank Kulman
New York Univ., New York, N. Y.	W. R. Steeneck	H. A. Weber
North Carolina State College, Raleigh, N. C.	F. P. Dickens	H. Baum
North Carolina, Univ. of, Chapel Hill	H. Klingenschmitt	J. D. McConnell
North Dakota, Univ. of, University	V. L. Cox	O. B. Medalen
Northeastern Univ., Boston, Mass.	F. W. Morley	L. C. Tyack
Notre Dame, Univ. of, Notre Dame, Ind.	C. A. Rogge	J. T. Burton
Ohio Northern Univ., Ada, Ohio	H. N. Seslar	Frank Boulton
Ohio State Univ., Columbus, O.	L. W. Hendershott	F. S. Kinkead
Oklahoma A. & M. Coll., Stillwater	B. Wrigley	K. Woodyard
Oklahoma, Univ. of, Norman, Okla.	F. O. Bond	E. F. Durbeck, Jr.
Oregon Agri. Coll., Corvallis, Ore.	H. E. Rhoads	B. E. Plowman
Pennsylvania State Collge, State College, Pa.	W. L. Kochler	J. E. Hogan
Pennsylvania, Univ. of, Philadelphia	P. K. Welch	J. G. Haydock
Pittsburgh, Univ. of, Pittsburgh, Pa.	S. A. Swetonic	L. M. Brush
Purdue Univ., Lafayette, Ind.	W. O. Osbon	R. C. Parker
Rensselaer Poly. Inst., Troy, N. Y.	F. M. Sebast	K. C. Wilsey
Rhode Island State Coll., Kingston, R.I.	D. B. Brown	S. J. Bragg
Rose Poly. Inst., Terre Haute, Ind.	J. H Utt	E. Letsinger
Rutgers University, New Brunswick, N. J.	Stanley Hunt	S. B. Aylsworth
South Dakota State School of Mines, Rapid City, S. D.	J. V. Walrod	C. Allen
South Dakota, Univ. of, Vermillion, S. D.	L. J. Stverak	R. T. Brackett
Southern California, Univ. of, Los Angeles, Calif.	H. B. Wilcox	W. T. Scott
Stanford Univ., Stanford University, Calif.	F. E. Crever	C. R. Walling
Stevens Institute of Technology		
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Syracuse Univ., Syracuse, N. Y.	K. N. Cook	R. H. Watkins
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Texas, Univ. of, Austin, Tex.	A. A. Bown	J. B. Coltharp
Utah, Univ. of, Salt Lake City, Utah	F. C. Bates	C. E. Hoffman
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Virginia Poly. Inst., Blacksburg, Va.	M. R. Staley	R. M. Hutcheson
Virginia, Univ. of, University, Va.	T. M. Linville	H. M. Dixon
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Wisconsin, Univ. of, Madison, Wis.	N. G. Robisch	Stanley Roland
Worcester Polytechnic Inst., Worcester, Mass.	O. H. Brewster	R. A Beth
Wyoming, University of, Laramie, Wyo.	E. Murray	V. D. Shinburn
Yale Univ., New Haven, Conn.	S. A. Tucker	G. C. Bailey
Total 84		

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies.

Motors.—Bulletin 137, 12 pp. Describes Wagner wound-rotor, slip-ring, polyphase motors. Wagner Electric Corporation, St. Louis, Mo.

Circuit Breakers.—Bulletin 9000, 12 pp. Describes Pacific multi-break oil circuit breakers. Pacific Electric & Manufacturing Company, 5815 Third Street, San Francisco, Cal.

Transformers.—Bulletin 2050, 4 pp. Describes Pittsburgh polyphase transformers, and discusses the importance of low exciting current and its value in the operation of transformers. Pittsburgh Transformer Company, Columbus & Preble Avenues, Pittsburgh, Pa.

Outdoor Substations.—The December 15 issue of the "Delta-Star Monthly," published by the Delta Star Electric Company, 2400 Block Fulton Street, Chicago, contains an interesting description of a standard outdoor substation construction for voltages up to 132 kv.

Electrical Drives for Power Plant Auxiliaries.—Bulletin 7381, 24 pp. Describes the advantages of motor driven power plant auxiliaries, including pumps, fans and blowers, coal handling equipment, pulverized fuel equipment, etc. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Illuminating and Wiring Equipment.—Catalog 24, 182 pp. Describes Benjamin electrical products, which include reflector-sockets, outdoor lighting fixtures, store and office lighting equipment, industrial signals, wiring devices, etc., Benjamin Electric Manufacturing Company, 120 So. Sangamon Street, Chicago, Ill.

Block Signals On a Steam Railway.—Bulletin 146, 100 pp., entitled "Alternating Current Signals on the Southern." The installation described covers 667 continuous miles of double track and presents a good example of the applicability of this type of signal system on a steam railroad where average track conditions prevail. General Railway Signal Company, Rochester, N. Y.

General Electric Catalog No. 6001 B.—Supersedes all previous catalogs issued by the company, except those dealing with railway, mine and industrial supplies and merchandise products. This complete catalog is issued every two years. The book is two inches thick and contains more than 1100 pages, the illustrations total more than 3200. The catalog is thumb-indexed into sixteen sections, as follows: Generation, wire and cable, distribution transformers, arresters, voltage regulators, switchboards and accessories, meters and instruments, motors, motor applications, industrial control, railway, lighting, industrial heating, miscellaneous and indexes.

NOTES OF INDUSTRY

Union Electric Manufacturing Company, Milwaukee, Wis., manufacturers of electric motor control equipment, announce the opening of a New York office in the Hudson Terminal Building, 30 Church Street, under the direction of A. J. Heidt.

Simplex Wire & Cable Company, Boston, Mass., has opened a branch office in the Lew Building, St. Augustine, Fla., in order to better care for the steadily increasing volume of business in this state. F. H. Pettee, who has represented the company in Florida for a number of years will be manager of the new office.

The Gray Instrument Company, 64 W. Johnson St., Germantown, Philadelphia, has been organized by J. G. Gray, formerly president of Queen & Company, Inc., and Queen-Gray Company. The new company will continue the manufacture of the line of electrical measuring and scientific instruments made for many years by the above named companies.

The J. G. White Engineering Corporation, New York, which has a contract with the Firestone Plantations Company to construct a harbor, breakwater, wharves, roads, etc., for the Government of Liberia at Monrovia, West Africa, recently sent a construction organization via England on the steamship President Roosevelt. Plant, tools, equipment and all necessary supplies also went forward on the same day, via the steamship West Humhaw, sailing direct to Monrovia.

Electrification of Chilean Mines.—The Andes Copper Company and the Chilean Exploration Company, both of Chile, have placed with the Westinghouse Electric & Manufacturing Company, orders totalling twenty-three industrial electric locomotives for the purpose of inaugurating the electrification of the haulage systems of these two mining properties. The complete electrification eventually will require some fifty additional 70-ton locomotives. The electric power for the haulage system at the Chile Exploration Company is generated by steam turbines and oil fired boilers located at the seacoast seventy-five miles away, and transmitted to the mining property at 110,000 volts.

General Electric Company Secures Manufacturing Site in St. Louis.—Gerard Swope, President of the General Electric Company, has announced that the company has definitely decided to purchase a site for a manufacturing establishment in the City of St. Louis. The tracts of real estate selected contain in the aggregate about 155 acres, of which all but 11 acres are within the city limits of St. Louis; the balance lies just beyond the city limits in St. Louis County. The property in general lies between the Belt Line of the Terminal Railroad Association and Goodfellow Avenue. It also has a frontage on Bircher Avenue.

Increase in Foreign Trade During 1925.—The Director of the Bureau of Foreign and Domestic Commerce reports that the export trade of the United States during 1925 continued its steady advance, exceeding by more than 7% its value in 1924. The total value of our exports for the year is in the neighborhood of $4,900,000,000, the largest figure since 1920. British exports of domestic products were slightly less than in 1924, and French exports also showed a decline. Those of Germany increased about 6%.

Exports of electrical machinery, in contrast with the normal increase in recent years, have been stationary. The increase of recent years in exports of copper was continued during 1925.

Buffalo General Electric Company Expands.—The rapidly increasing load supplied by the Niagara system, and the necessity of maintaining a proper balance in the supply of steam and hydro-power have made it necessary to add a 60,000 kw. turbine to the equipment of the River Station of the Buffalo General Electric Company. The construction schedule calls for the new unit to be in operation early in the fall of 1926. The River Station at present includes three 20,000 kw. and one 35,000 kw. turbine generators. These, as well as the new unit now to be added, are of General Electric manufacture.

Western Electric Creates New Company.—The electrical supply business carried on by the Western Electric Company has been set apart from the telephone manufacturing business and incorporated under the name of Graybar Electric Company. The Western Electric Company has been both the manufacturing company of the Bell System and a distributor of electrical supplies. Both of these lines of business require specialized organization and specialized management. The rapid expansion of the supply department made an entirely separate corporate identity even more necessary.

The new company is capitalized at $15,000,000, all owned by the Western Electric Company. The officers are as follows: Charles G. DuBois, president of the Western Electric Company, is chairman of the Board; Albert L. Salt, president; Frank A. Ketcham, George E. Cullinan, Leo M. Dunn and Howard A. Halligan, vice-presidents; Richard H. Gregory, comptroller.